A NEW ARCHITECTURE FOR FIBER-OPTIC SUBSCRIBER ACCESS NETWORK AND EFFECT OF SEMICONDUCTOR OPTICAL AMPLIFIERS (SOAs) ON IT

by

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CERTIFICATE

This is to certify that the thesis work entitled **A New Architecture For Fiber-Op Subscriber Access Network And Effect of Semiconductor Optical Amplifiers** it by *A.Sakthivel*, *Roll No.* 9712405 has been carried out under my supervision and same has not been submitted elsewhere for a degree.

July,1998

Dr. Y.N.Singh,
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Dedicated

To

My Beloved Parents

and

My Thesis Supervisor

Acknowledgments

I express my sincere thanks to *Dr. Y. N Singh*, my thesis supervisor for his inval able guidance and encouragement given to me through out my thesis. I am grateful to for his suggestions and advises He has always been very patient during the thesis work.

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Last but not the least I wish to acknowledge the constant encouragement, supp blessings and guidance which my parents gave me.

(A. SAKTHIVEL)

Abstract

Subscriber Access Networks (SAN) are used to connect central office and customer premises In this thesis all-optical network SANs are considered Many SAN architectures have already been proposed in the past. Here, a new architecture for the local loop is designed and proposed. The supportable number of users is computed with and without optical amplifier. The effect of gain saturation of the amplifier and the extinction ratio are also analyzed. The total cost per subscriber in the proposed architecture is less because the equipments and fiber costs are shared by many customers The network is suitable for Gigabits transmission. The optical amplifiers play an important role in system upgrdation. The semiconductor laser amplifiers (SLA) are used in the network to increase the supportability. In the network, not only supportable number of users are increased by using OAs but also the transmission distance.

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Chapter 1

Introduction

The application of optical technology to the local network has been a field of increasing interest and debate over the past few years In the past it has usually been assumed that optical networks will penetrate to small business and residential customers only if new wide-band services are provided that will gain extra revenue to offset the aditional costs involved in the provision of optical technology but the revenue is uncertain and it is very difficult to pre-estimate the demands. To tackle this problem networks must be designed in such way that they should not give much economic burden and are compatible with exsisting services.

The local loop or subscriber access network which lies between the central office and a subscriber location is a part of the telephone plant and is considered mainly a twisted pair copper cable. The subscriber loop has undergone many changes over the past few years. Today stage is set for cost effective extention of fiber to the subscriber. One of the challenges in providing cost effective subscriber loop transmission systems is to develop low cost optical source and detector compatible with high volume manufacturing environment. In this chapter, a general structure of the local network and the major options are described. Some examples of the local access network are also given.

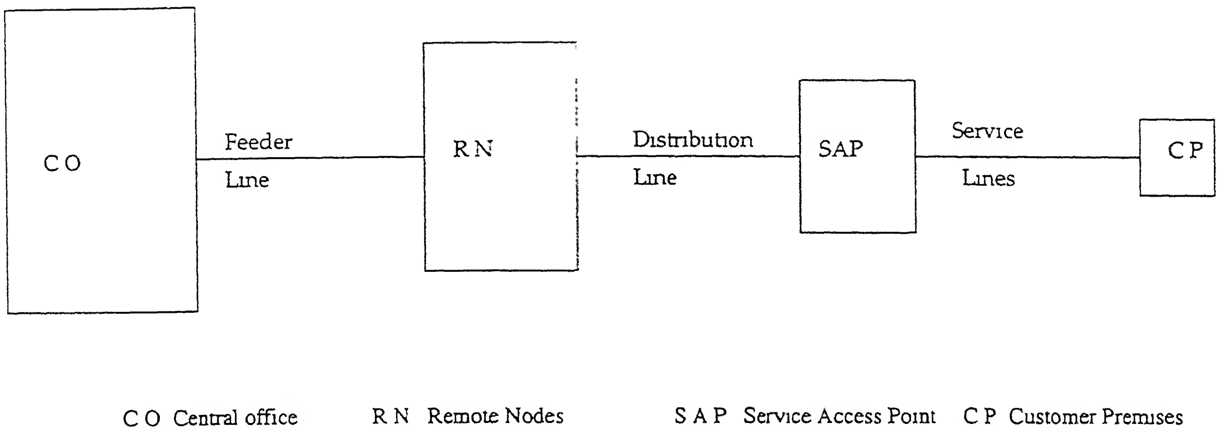

Figure 1.1: Subscriber Access Network Model

1.1 Subsriber Access Network

Subscriber access network is an all-optical network which connects customers to a central or switching office (CO). Communication link is made between two subscribers via exchange and the telecommunication network. The traffic flow control and management (administration) is done by the exchange. The feeder, distribution, and service cables may be totally fiber-based; however near-term economic considerations may call for deploying fiber only upto the SAP and using Copper (wire pairs or coax) for the service segment [8]. The enhanced bandwidth offered by optical fiber will allow the use of subscriber access networks to provide wide-band services (videophone, HDTV, Video on demand, Digital audio and video, facsimile, data etc) to the subscriber together with the narrow band services.

Each segment of the subscriber access network (feeder, distribution, service) may have different physical topology, which refers to certain physical attributes of that segment.

1.2 Topologies

The manner in which nodes are geometrically arranged and connected is known as the topology of the network. There can be physical as well as logical toplogies *Physical topology* is the physical interconnection pattern while the *Logical topology* is the pattern in which information flows [8]

There are three major classes of topologies *bus*, *ring* and *star*. Each of these topologies has its own particular advantages and limitations in terms of reliability, expandability, and performance characteristics.

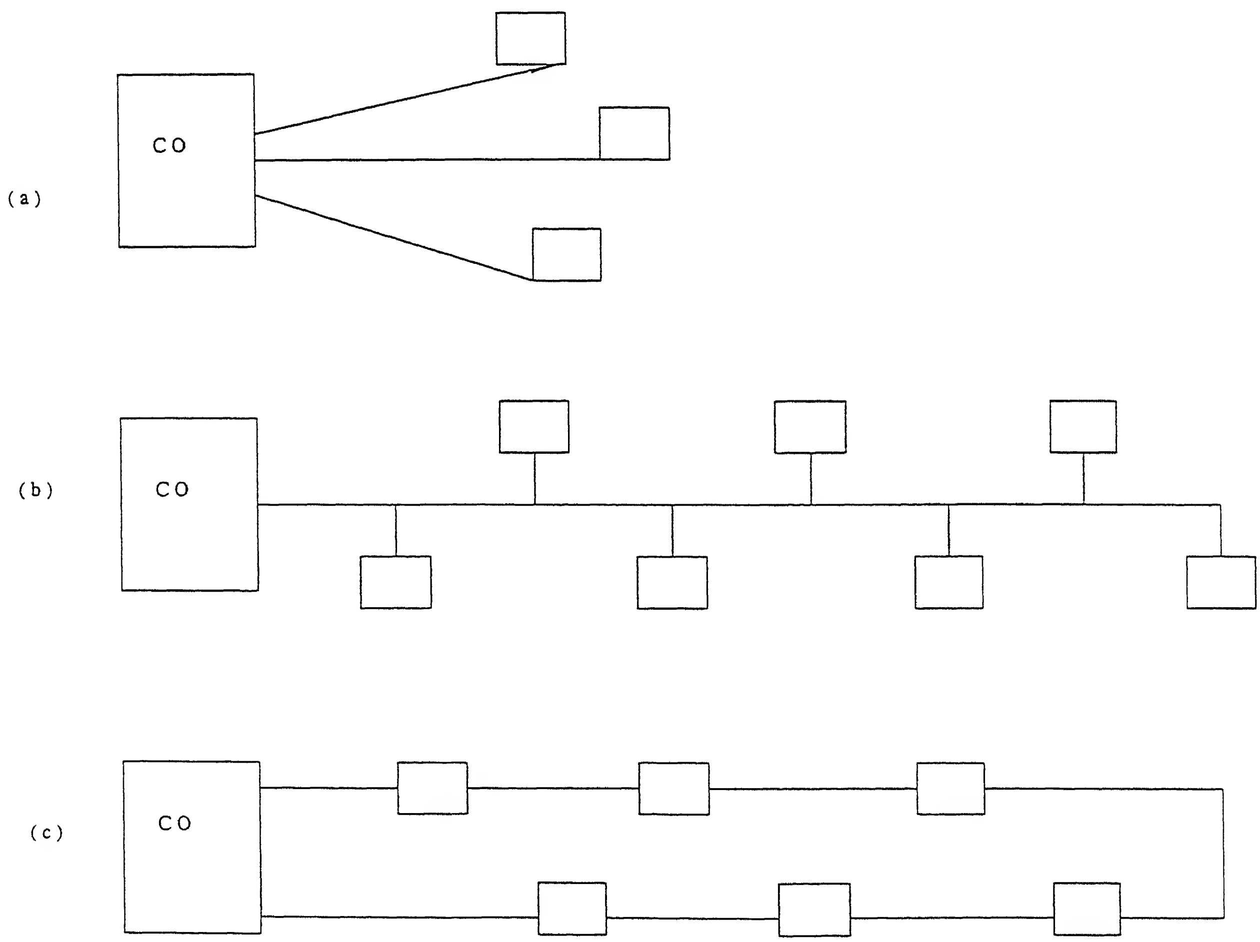

Figure 1.2: Topologies:(a) Star (b) Bus (c) Ring

Many factors must be considered in comparing the topological alternative for the various segments of the loop. These factors include initial cost, life cycle cost, available technology, evolvability to future network architectures, flexibility in providing future services, network reliability and maintainability and customer concerns regarding privacy and security.

1.2.1 Bus Topology

The bus topology is shown in figure 1.2 (b). In a bus topology all the network nodes are connected to a common transmission medium. Each network node has a unique address which is used when information is transmitted. When a message is sent it propagates throughout the medium and is received by all the users To receive messages, each user continuously monitors the medium and copies those messages that are addressed to it as the messages go by

Since the transmission medium in a bus is generally time-shared and broadcast in nature there must be some type of control mechanism to prevent several users from transmitting simultaneously. These mechanisms are generally classified as *polling* or *contention* techniques (random access).

Advantages

- Cable runs are shorter than in other topologies
- Ideally suited for use with high performance contention protocols.
- The station can be added or removed without disturbing the other stations. Suitable media access techniques can also be used, which are unaffected by addition or deletion of station.

- Failure of any station does not affect the operation of the other stations. The fiber cable used as a transmission media is highly reliable and usually doesn't fail Consequently a network has very high reliability.

Disadvantages

- Transmission distance is restricted because optical power at a particular user's receiver decreases with increasing distance Thus an important parameter of interest is the maximum optical power range (dynamic range) to which any receiver must be able to respond The smallest difference in transmitted and received optical power occurs for adjacent users. The largest difference in transmitted and received optical power occurs between the first user and the farthest one restrictions
- Access to an optical fiber is achived by means of coupling (tapping). Insertion and output losses at each tap plus the fiber losses between taps limit the network size to a small number of users.

1.2.2 Ring Topology

The ring topology is shown in figure 1.2 (c). In this topology consecutive nodes are connected by point-to-point links which are arranged to form a single closed path The merits and demerits of the topology are as follows

- rings must be physically arranged so that all nodes are fully connected
- whenever a node is added to support new services, transmission lines have to be placed between this node and its two nearby, topologically adjacent nodes This addition or deletion of node disturbs operation of the network unlike the bus

- Break in any link, failure of any node will disrupt network operation Therefore network will be much less reliable than the bus As all the nodes must be kept ON for network operation, this topology is generally used as back bonei

- higher speed interfaces are desirable so that fiber bandwidth can be used to full extent

- fault sectionalization is more difficult as the whole network becomes nonoperational unlike bus or star whenever fault occurs

- low reliability because the network insecure like the bus as the information is broadcast But the communication can be interrupted by intermediate node because broadcast is achieved by relaying the information. This is also one of the reasons why this topology is preferred in backbone

1.2.3 Star Topology

In star topology dedicated fibers are used to connect each subscriber The advantages and disadvantages of this topology are as follows

- Amount of cable required is considerably increased over the ring or the bus network.

- Simple user equipment is adequate as dynamic range of receiver need not be as large as needed in bus topology.

- Network expansion is limited due to fixed dimension of star coupler

- More bandwidth is available as compare to ring topology

- Sectionalization of faults is easy

- High reliablility as node failures does not effect the connectivity.

- high degree of security and limit unauthorized access due to dedicated fiber facility but result in a higher initial cost However, when the distances are short then the initial cost is immaterial.

1.3 Local access network systems

Several fiber based local access network systems are described as examples to illustrate the architectural concepts described above

1.3.1 Totally Transparent Optical Subscriber System (TTOSS)

The totally transparent optical subscriber system is shown in figure 1 3 It is a single star topology used between CO and CP Thus, dedicated fibers required between CO and each customer Two fibers can be provided to each customer One for each direction of transmission or both directions of transmission can be carried over a single fiber using an optical duplexer to separate the downstream wavelengths from the upstream wavelengths [11] WDM techniques are used to provide multiple optical channels to each customer in the TTOSS system. The major advantages are :

- ease upgradation of the system.
- high reliability and low maintaince
- privacy and security.

1.3.2 Telephony Passive Optical Network (TPON)

The telephony passive optical network is shown in figure 1 4. It is a physical star and logical bus topology used in the feeder, distribution and service segments of the local access network, which uses a broadcast mechanism for communication [12]. In TPON the customer security and privacy are needed encryption and time slot hopping can also be used An optical

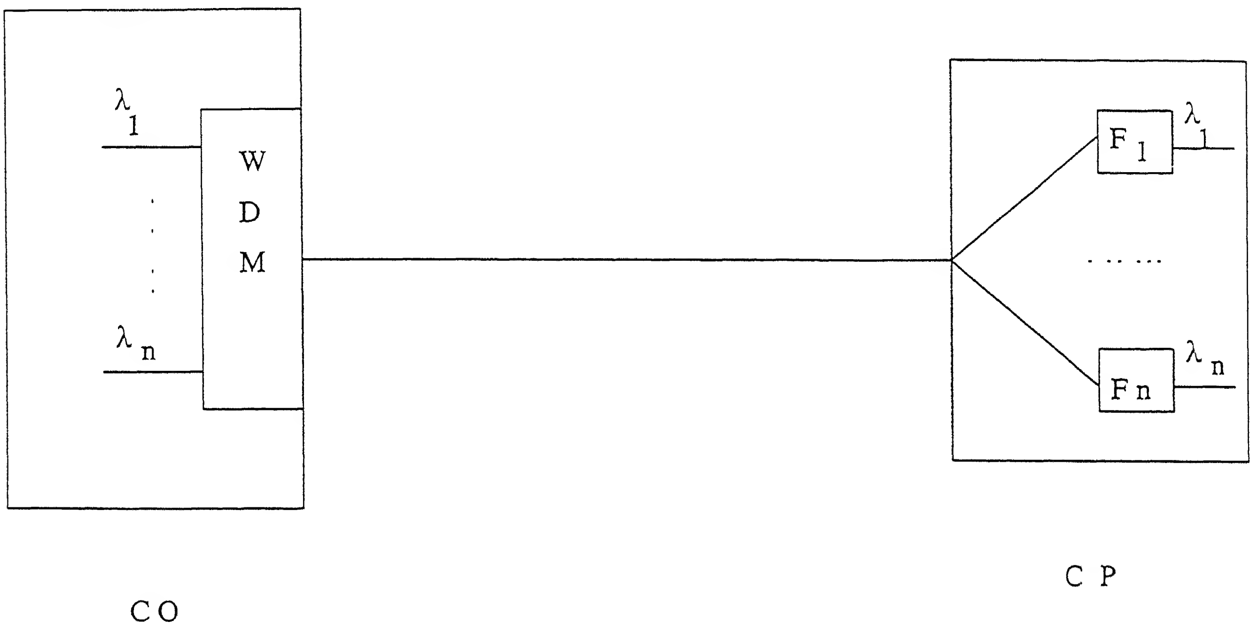

Figure 1.3 Totally transparent optical subscriber system

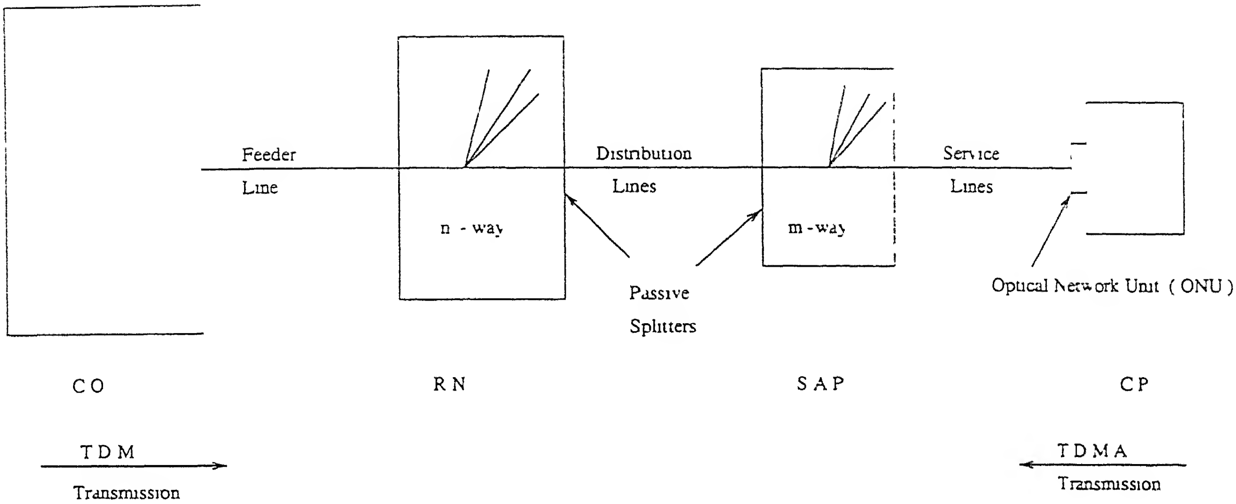

Figure 1 4 Telephony passive optical network

filter that passes only the TPON system wavelength is built into the ONU. This enables wavelengths to be added at a latter date to provide new services without disturbing the existing telephony and ISDN services These new services can use FDM,TDM or ATM multiplexing techniques [12]. To maintain the same bit error rate, the higher bandwidth required for broad band services requires a higher signal-to-noise ratio as they use large bandwidth Evolution from TPON to BPON may require the addition of fibers in the feeder segment to bypass some of the multistage splitters

1.3.3 Passive Photonic Loop (PPL)

Passive Photonic Loop system is shown in figure(1 5) It is a double-star network and uses *dense* WDM techniques to provide each customer with a dedicated downstream wavelength and a dedicated upstream wavelength [10]. Here *dense* means that large number of wavelengths are used within narrow spectrum. A grating based dense WDM device can support upto 50 wavelengths [9]

The PPL system allows sharing of the fiber by several customers. Dense WDM is

used between the CO and RN or SAP to allow sharing of the single feeder fiber Dedicated optical fiber links connect the RN or SAP to CP

Thus. PPL has a physical star and logical star topology in both the feeder and the service segments of the local access network In PPL the Dense WDM devices at the SAP rather than the RN would increase not only the sharing of fiber. but also increases the number of equipment locations that must be administered [13,10]

Very narrow line widths are required for dense WDM systems Therefore distributed feedback (DFB) laser transmitters are necessary [10] Basic PPL design can be combined with a broadcast overlay for upgradation Several broadcast signals may be multiplexed at the CO using FDM, WDM, TDM or ATM techniques and transmitted to the RN, where passive power splitters split the signal for delivery to the customers

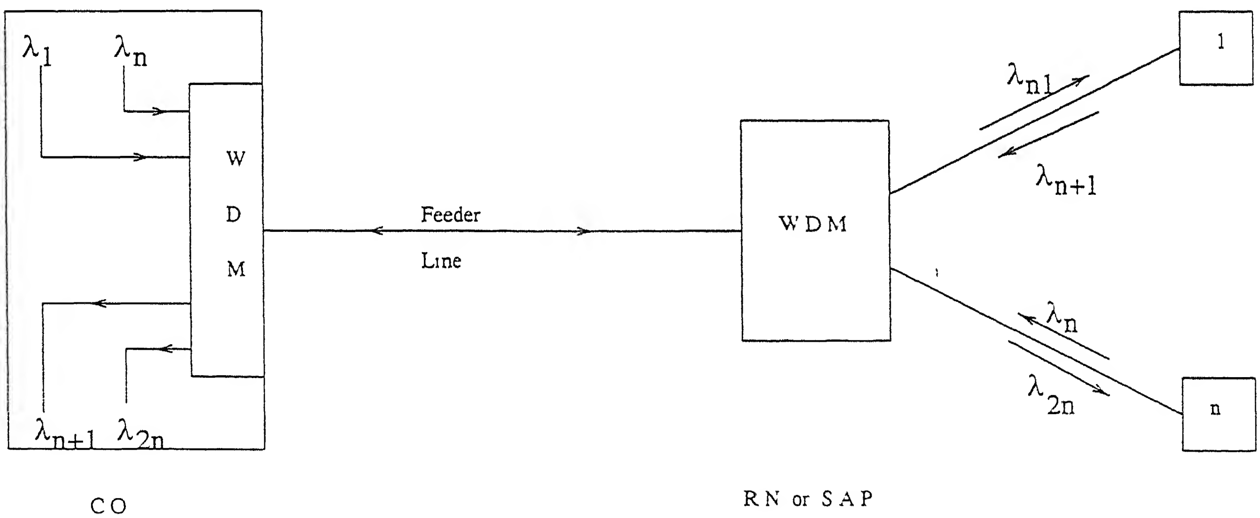

Figure 1.5 Passive photonic loop

In the following chapters a new subscriber access network architecture is proposed and analysed. This network may resultin low installation cost and maintaince cost It is high capacity, symmetrical, and twoway broadband service network. The overall cost per customer will be less because most of the equipments and fiber cost are shared by groups of customers.

Chapter 2

System Architecture

In this chapter a new fiber-optic subscriber access network architecture is proposed It is more suitable for high capacity transmission of the order of gigabits per seconds. Time division multiplexing (TDM) with reservation access technique is used to avoid collision in both upstream and downstream direction It is a symmetric service system. The key components such as wavelength division multiplexing (WDM) device, optical add-drop multiplexer (OADM) devices and Star coupler (SC) are used with wavelength *reuse technique.*

2.1 Network Configuration

The new architecture shown in figure(2 1) is a combination of a bus and star topology. Basically, it is considered as a physical bus and a logical star network. The architecture has two buses, one for downstream transmission and one for upstream transmission Both the buses carry multiple wavelengths. There are OADM devices on each bus. For downstream transmission OADM drops the wavelengths at various locations [14]. There are N such OADM devices on each bus. As shown in figure(2.1) the dropped signal is fed to a star

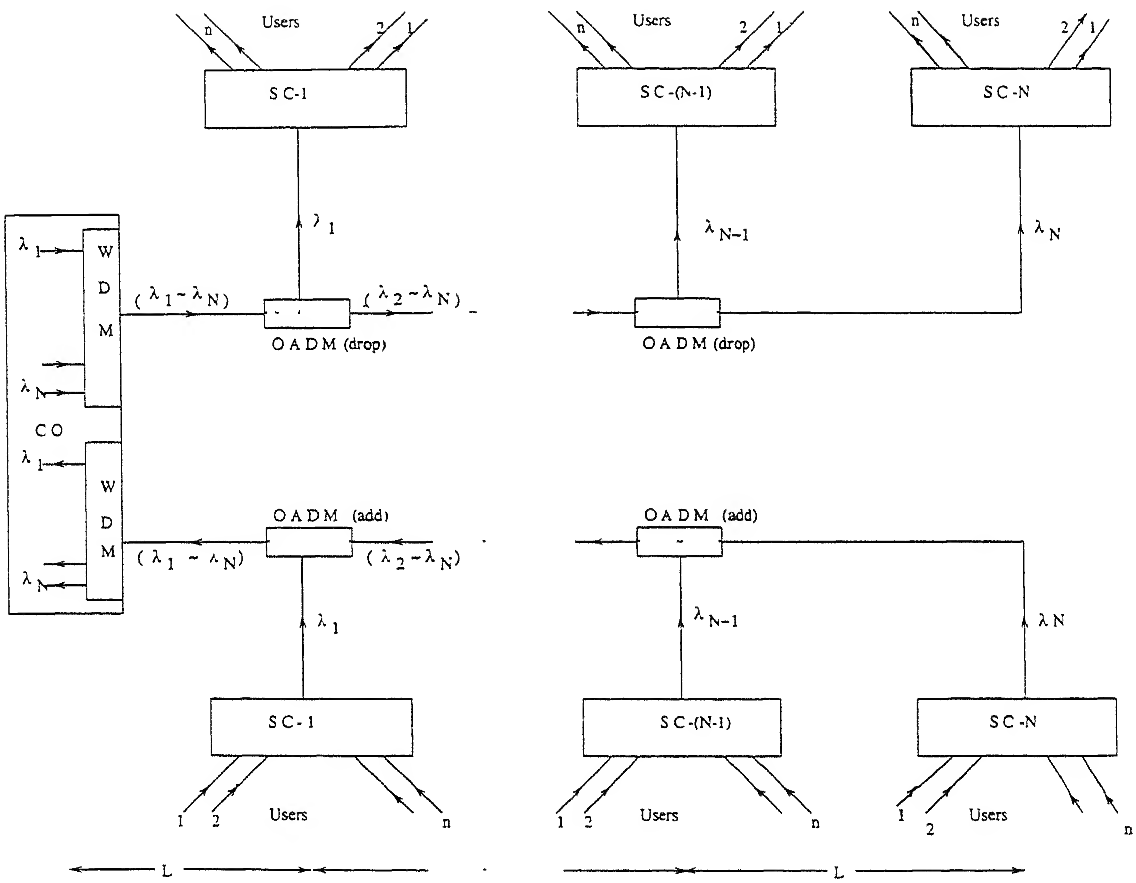

Figure 2 1: Configuration of new architecture

coupler, which splits it The splitted signal is distributed to the subscribers connected to star coupler through a dedicated fiber Each of these star coupler supports n subscribers The n subscribers form a group

A specific wavelength is preassigned to each group and the same wavelength is dropped from a set of wavelengths in the bus

The signal on this wavelength is equally distributed to all n users through a star coupler(SC). The same wavelength is used by the same n subscribers in the group for upstream transmission. Thus, the same wavelength used by a group of n users in both upstream and downstream direction procedure is called *wavelength reuse* scheme [14]

In a single bus or ring network where adding and dropping of a signal of the same wavelength takes place simultaneously the interference beat noise affects the receiver sensitivity more severely compared to the wavelength not-reuse scheme

In this topology, the total number of users, N_u , can increase as $2^i n$ where i is an integer and n is the number of users per group(branch) There are N number of branches and hence the number of channels are assumed to be N

The maximum number of users, n_{max}, in a group is limited by the nature of service and the minimum bandwidth required for that service by individual user For example if B is the bit rate in bits/sec then the maximum number of user per group is equal to B divided by the minimum bandwidth needed by each customer Once the maximum number of users is fixed, then the network size is limited by the various losses between transmitter and receiver since the optical power available at a particular user's receiver decreases with increasing distance form the source

2.2 Devices used

The key components used in this network are wavelength division multiplexer (WDM), Optical Add-Drop multiplexer (OADM) and Star Coupler(SC)

2.2.1 Optical Add-Drop Multiplexer

Mach-Zehnder interferometers with fiber Bragg grating (MZ-FG) have been investigated as promising devices for wavelength selectable optical add-drop multiplexers (OADM) [14]. The optical add-drop multiplexer is expected to play an important role enabling greater connectivity and flexibility in WDM networks Cascaded MZ-FG's have been fabricated to show that the interferometric crosstalk can be successfully reduced to -50 dB for the add signal, and -71 dB for the drop signal, respectively. Individual MZ-FG has reflection of 3 dB and 20 dB for corresponding reflection bandwidths 0.8 and 1.5nm respectively. The insertion loss is 0 7 dB for droping, and 0 50 dB for adding. The crosstalkfree bandwidth of 0.6 nm was also obtained with the cross talk of less than -35 dB . No BER degradation was observed in both add and drop performances [14]

2.2.2 Wavelength division multiplexer (WDM)

Arrayed-waveguide grating (AWG) multiplexers/demultiplexers are key components in wavelength division multiplexing transmission systems and networks The crosstalk of an arrayed-waveguide grating multiplexer/demultiplexers was reduced by employing a phase compensating plate developed for static phase control Experimental results showed as low crosstalk as -37 dB and -39 dB for the TE and TM modes respectively. It is also reported that the insertion loss is less than 1 dB and the device is polarization independent. The channel spacing is 0.8 nm in 1.55 μm band ($100GH_z$) [15].

2.2.3 Star Coupler

Star Couplers are generally used for distributing a single input signal to multiple outputs

Assume a $1 \times n$ splitter or $n \times 1$ combiner made of 3 dB 2×2 couplers The signal passing through it must transverse $log_2 n$ couplers. If L_d is insertion loss of a single 3 dB 2×2coupler then, total insertion loss is $L_d \; log_2 n$ and the splitting /combing loss $10 log_{10} n$. Thus the total loss due to SC is the sum of the insertion loss and splitting loss

2.3 Advantages

The proposed architecture of local access network has the following features.

- Amount of fiber used in the feeder and distributive segments are less
- There is no active devices in the loop
- Initial cost is less since the equipment and fiber cost are shared by a group of users
- It is easy to reconfigure the network(add and remove users) without disturbing other users as the OADMs are used
- Network expansion is straightforward and increases the maximum potential bandwidth of network. Therefore it provides the maximum flexibility in service provisioning and in future upgradation
- The administration of bandwidth requirements for individual customers and the sectinalization of faults are simplified considerably
- The star coupler is placed near the customer premises so that the length of the dedicated lines is reduced thereby reducing the cost.

- The number of users supported by this network is large as compared to any other subscriber access network

Chapter 3

System Analysis

The optical power budget for a system is given by the following expression:

$$P_T = P_R + L + M_a \quad dB \tag{3.1}$$

where P_T is the average optical power transmitted, P_R the average optical power required at the receiver and L the total channel loss. The safety margin M_a is to include in the power budget to avoid unacceptable decrease in system performance due to small variations in the system parameters

3.1 Power Budget Analysis

The system model for Powerbudget analysis is shown in figure(3 1) To determine the supportable number of users for the given transmitter power and bit error rate (BER) it is assumed that all the users in a group are at equal distance from the access point (SC). The branches are equally spaced and equal to the number of wavelengths

The following symbols are used in the analysis:

- transmitter optical power per channel, P_T, dBm
- optical power received at branch P_{bk}, dBm where $k = 1, 2, 3, \ldots, N$
- single splice loss, L_s, dB
- fiber attenuation α, dB/km
- fiber loss, L_f, dB
- insertion loss of WDM, L_w, dB
- insertion loss for droping signal in ADM, L_{13}, dB
- insertion loss for adding signal in ADM, L_{12}, dB
- insertion loss of single 3 dB 2×2 coupler, L_d, dB
- distance between branches, L, km
- total number of branches which is equal to number of wavelengths, N
- number of users per branch, n

Power received at branch-1, P_{b1}, is given by

$$P_{b1} = P_T - L_w - 4\, L_{sp} - L_{12} - \alpha\, L. \qquad ($$

power received at branch-2

$$P_{b2} = P_T - L_w - 6\, L_{sp} - L_{13} - 2\, \alpha\, L. \qquad ($$

and power at branch-3

$$P_{b3} = P_T - L_w - 8\, L_{sp} - 2\, L_{13} - L_{12} - 3\, \alpha\, L \qquad ($$

and so on. Hence the power available at branch-N is given by.

$$P_{bN} = P_T - L_w - 2\, (N+1)\, L_{sp} - (N-1)\, L_{13} - L_{12} - N\, \alpha\, L. \qquad ($$

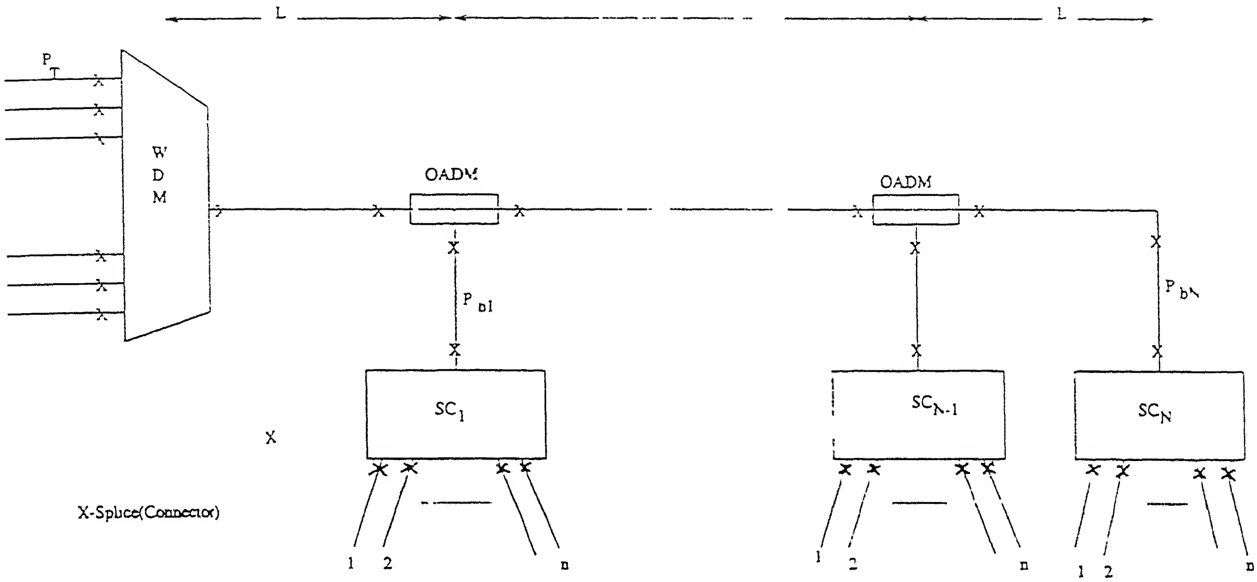

Figure 3.1 System model

At the branch-N the power received is minimum and the total loss between the transmitter and receiver is maximum Therefore, it is considered as the worst case for the analysis The power received at each branch is equally divided among the n users through a star coupler (SC)

The optical power available at a receiver is equal to the optical power available at the branch minus the coupler losses The minimum optical power required at the receiver is equivalent to its sensitivity in order to maintain a particular BER for given bit rate. The receiver sensitivity is defined as the minimum optical input power (measured in dBm) for which the BER measured at the receiver is 10^{-9} [7]

For bit rates between 10 Mb/s and 2.5 Gb/s and over the wavelength range of 0.8 – 1 6 μm the best optical receivers require a flux of 300 – 1000 photons per bit corresponding to a sensitivity of

$$P_R = 2 \times 10^{-13}\, B \quad mW \tag{3 6}$$

where B is the bit rate in bits/sec per channel [6]

3.2 Computation of Supportability

The maximum number of users in a branch can be determined for given bit rate per channel on the basis of the minimum bandwidth required per user and the percentage of active users at a time Once the number of user per branch is fixed, the total number of branches and hence the maximum transmission distance can be determined in the following two ways Once the relationship between BER and P_T is known for a given N, the minimum required P_T can be determined using this relation in order to maintain a particular BER Otherwise, by using the same relation the maximum BER required for given P_T and N is computed. In either case the total number of users which is product of total number of branches and the number of users per branch, is the same The relation is derived as follows The power received at photo detector 9PD) for bit i (i is either 1 or 0) is given by

$$P_R(i) = P_s(i)\, L_{TR} \tag{3.7}$$

where

$$P_s(1) = \frac{2\, P_T}{1+\epsilon}$$

and

$$P_s(0) = \frac{2\, P_T\, \epsilon}{1+\epsilon}$$

In these equations, P_T represents the average transmitter power and ϵ the extinction ration (the ratio of the optical energy emitted in the 0 bit period to that emitting during 1 bit period). The loss L_{TR} between transmitter and receiver is given by

$$L_{TR}(\text{in } dB) = [L_w + 2(N+2)L_{sp} + (N-1)L_{13} + L_{12} + N\,\alpha\, L + 11.66 log_{10} n] \tag{3.8}$$

This includes the total losses of star coupler and two splices loss each at input and output of SC. The signal current and noise variance for bit i (i=0 or 1) at PD output are given by

$$I_s(i) = R_0 P_R(i) \tag{3.9}$$

$$\sigma^2(i) = 2\, e\, R_0\, P_R(i)\, B_e + \frac{4KTB_e}{R_L} \tag{3.10}$$

where K is the Blotzman constant, T the temperature in Kelvin, R_L the load resistance of the PD, R_0 the responsivity of the PD, e the charge of electron and B_e, the electrical bandwidth of the receiver. The average probability of error considering the threshold level which equalizes the BER for bit 1 and 0 is

$$P_e = \frac{1}{2} erfc \left[\frac{I_s(1) - I_s(0)}{\sqrt{2}[\sigma(0) + \sigma(1)]} \right] \tag{3.11}$$

Chapter 4

System Upgradation by Using Optical Amplifiers

Optical amplifiers, as their name implies, operate only in the optical domain with no inter conversion of photons to electrons. There are two types of OAs: Semiconductor Optical Amplifiers (SOAs) and Doped Fiber Amplifiers (DFAs). Both these work on the principle of stimulated emission. They only differ in the method of pumping SOAs are electrically pumped and DFAs are optically pumped. Fiber amplifier can also be based on the stimulated Raman or Brillouin scattering [6]. Both SOA and DFA have the ability to provide high gain over wide spectral bandwidths making them eminently suitable for future optical fiber system applications

The advent of SOA and fiber amplifier accelerated the pace of deployment of high-capacity lightwave systems. These amplifiers can boost the power of the lightwave signals without the need for optoelectronic conversion and subsequent electronic amplification as in conventional lightwave repeaters [5] Another advantage of optical amplifier is that data on many wavelength can be simultaneously amplifier.

Optical amplifiers enable flexible design of transmission systems with the potential of bit rate transparency and of capacity enhancement through WDM channels The main purpose of the optical amplifiers is only to restore signal powers in the system so that the SNR remains acceptably high every where in the system. They do not reconstitute a transmitted signal and therefore the noise and signal distortion accumulates with each amplifier stage Optical amplifiers can be used in a broad range of system applications namely, as power amplifiers at the optical transmitter, as in-line amplifier, and as preamplifier at optical receivers.

SLAs are preferred to fiber amplifiers as they exhibit low power consumption and their single-mode waveguide structures make them particularly appropriate for use with single-mode fiber They can be easily integrated with transmitter, receiver or integrated optic devices Therefore SLAs have been considered in the following analysis

4.1 Amplifier Model

An SLA can be represented by a traveling wave amplifiers (TWA) model as shown in the figure(4 1). If $G\sqrt{R_1 R2} < 0.17$, where R_1 and R_2 are the reflection coefficients of two facets of the amplifiers, and G, the single-pass saturated gain [2,7] Gain of these amplifiers reduces with the increase in input optical power level This is referred to as gain saturation. The saturated gain G of the amplifier is obtained by solving the following non linear equation :

$$G = G_0\, exp\left(-\left(G-1\right)\frac{P_{in}}{P_{sat}}\right) \tag{4.1}$$

where G_0 is the unsaturated gain, P_{in} the total input optical power, P_{sat} the saturation power level The G_0 and P_{sat} are the amplifiers parameters [2].

Noise is an inherent characteristic of optical signals This can be understood by

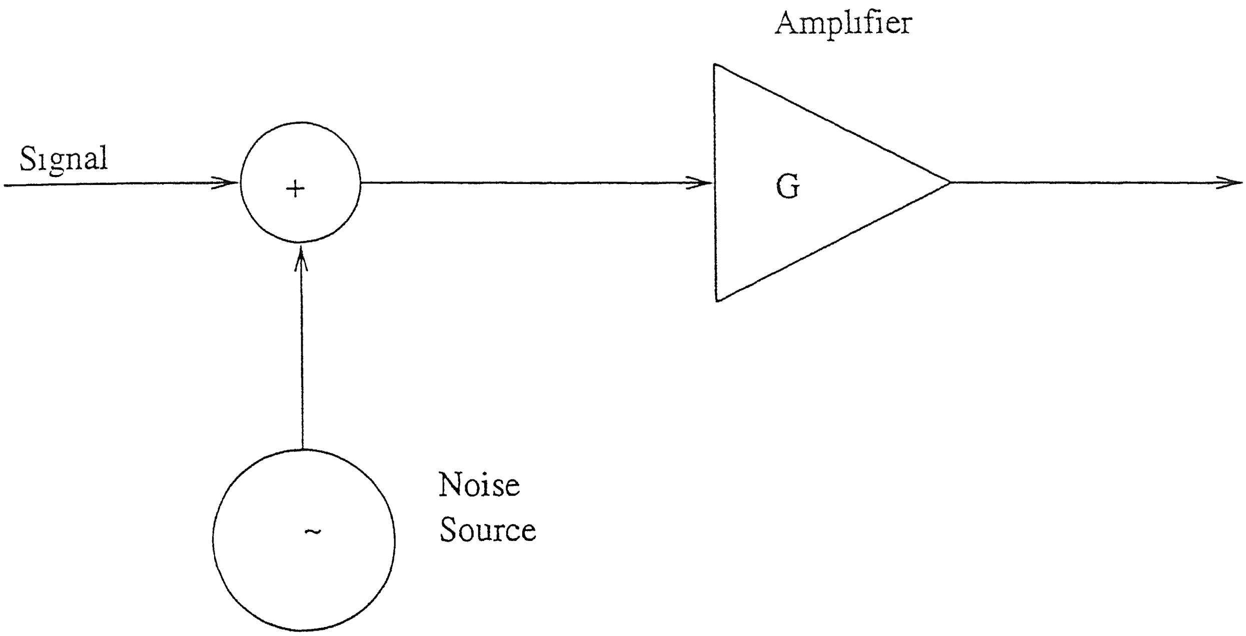

Figure 4 1· Optical amplifier model

using elementary quantum mechanics and the Heisenberg uncertainty principle. A bunch of photons of mean number $< n >$ produced by a coherent light source such as a laser, is characterized by Poisson counting statistics, whereas a thermal source, such as a light-emitting diode, has Bose-Einstein Statistics Although not strictly accurate, the noise statistics of the amplified light and photoelectrons are usually approximated as Gaussian [6]. The SLA's, in addition to amplified signals, also produce amplified spontaneous emission (ASE) noise This noise degrades the system performance. It is considered to be white with a single-sided power spectral density (PSD)

$$S_{sp} = n_{sp}\,(G - 1)\,h\nu \tag{4.2}$$

where n_{sp} is spontaneous emission noise factor, h is the Planck's constant, and ν the optical frequency [2].

At the photo detector (PD), the ASE noise beats with signal and itself to produce ASE-signal and ASE-ASE beat noise components. When ASE noise beats with itself, it also produces, a dc signal which is responsible for additional shot noise component. The

variances of different beat noise current components are [2] :

$$\sigma^2_{ASE-ASE} = R_0^2 S_{sp}^2 [2\, B_e B_0 - B_e^2] \tag{4.3}$$

$$\sigma^2_{ASE-sig} = 4\, R_0^2\, P_R\, S_{sp}\, B_e \tag{4.4}$$

and

$$\sigma^2_{ASE-shot} = 2\, e\, R_0 [S_{sp}\, B_0] B_e \tag{4.5}$$

In the above equations, R_0 is responsivity of PD, B_e the electrical bandwidth of receiver, B_0 the optical bandwidth and e the electron change

4.2 Network with Unsaturated amplifier

Supportable number of users can be increased by using optical amplifiers as power amplifiers. The amplifier placed at the output of WDM will act as power amplifier which amplifies multichannel WDM signals equally. The farthest user transmits more power as compared to nearer one in order to compensate the channel loss. Let a user in the branch N transmits and receives the powers P_{Tn} and P_{Rn} respectively and the amplifier gain is G. The total losses between the CO and a customer is the same for both upstream and downstream directions. The power budget analysis discussed for downstream path is also valid for the upstream path if the condition $G + 1 = k$ is satisfied In the above equation k represents the sum of P_{Tn} and P_{Rn}. It is assumed that the condition is satisfied in this analysis

For a given number of amplifiers the network may be able to support more users as compared to any other networks, when the amplifiers are placed at proper distance on the bus.

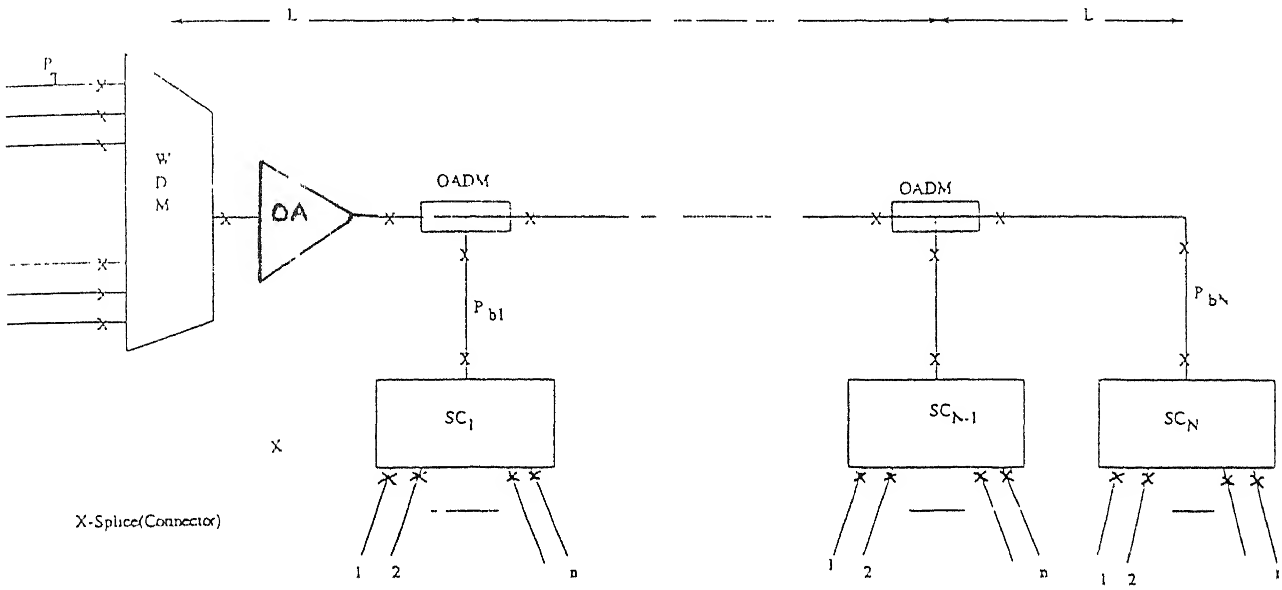

Figure 3.1: System model

At the branch-N the power received is minimum and the total loss between the transmitter and receiver is maximum. Therefore, it is considered as the worst case for the analysis. The power received at each branch is equally divided among the n users through a star coupler (SC).

The optical power available at a receiver is equal to the optical power available at the branch minus the coupler losses. The minimum optical power required at the receiver is equivalent to its sensitivity in order to maintain a particular BER for given bit rate. The receiver sensitivity is defined as the minimum optical input power (measured in dBm) for which the BER measured at the receiver is 10^{-9} [7].

For bit rates between 10 Mb/s and 2.5 Gb/s and over the wavelength range of 0.8 – 1.6 μm the best optical receivers require a flux of 300 – 1000 photons per bit corresponding to a sensitivity of

$$P_R = 2 \times 10^{-13}.B \quad mW \tag{3.6}$$

where B is the bit rate in bits/sec per channel [6].

Let the gain of unsaturated amplifier be G_0. The $P_R(i)$ at the receiver is given by

$$P_R(i) = P_S(i)\, G_0\, L_{TR} \tag{4.6}$$

The ASE noise psd at the receiver will be

$$S_{sp} = n_{sp}\,(G_0 - 1)\, h\, \nu\, L_{TR} \tag{4.7}$$

The signal current and noise variance for bit i are given by

$$I_s(i) = R_0\, P_R(i) \tag{4.8}$$

and

$$\begin{aligned}\sigma^2(i) = 2eR_0\left[P_R(i) + S_{sp}B_0\right]B_e + 4R_0^2 P_R(i) S_{sp} B_e + \\ R_0^2 S_{sp}^2\left[2B_0B_e - B_e^2\right] + \frac{4KTB_e}{R_L}\end{aligned} \tag{4.9}$$

The average probability of error with threshold level which equalizes the BER for bit 1 and 0 is determined by using equations (4.8) (4.9) and (3.11)

4.3 Network with Average gain Saturated amplifier

Let N_1 channels out of total N channels are having bit 1. The probability that N_1 channels are having bit 1 is given by

$$P_{N1} = \begin{pmatrix} N \\ N_1 \end{pmatrix} \left[\frac{1}{2}\right]^N \tag{4.10}$$

Here, the probability distribution of number of channels having bit1 is presumed to be binomial. The input power to the amplifier corresponding to bit i is

$$P_{in}(i) = P_s(i) \tag{4.11}$$

The total input power to the amplifier is $N_1\, P_{in}(1) + (N - N_1)P_{in}(0)$. The corresponding saturated gain $G(N_1)$ of the amplifier is computed using equation (4.1) with the above input power. The average gain is given by

$$G_{av} = \sum_{N_1=0}^{N} P_{N1} G(N_1) \tag{4.12}$$

The signal power received for bit i will be

$$P_R(i) = P_{in}(i) G_{av} L_{TR} \tag{4.13}$$

As G_{av} is independent of signal bit, the ASE noise psd for both bit 1 and 0 will be same. It is given by

$$S_{sp} = n_{sp}\left[G_{av} - 1\right] h\nu\, L - TR \tag{4.14}$$

The signal currents and noise variances are given by

$$I_s(i) = R_0\, P_R(i) \tag{4.15}$$

and

$$\sigma^2(i) = 2eR_0\left[P_R(i) + S_{sp}B_0\right]B_e + 4R_0^2 P_R(i) S_{sp} B_e +$$
$$R_0^2 S_{sp}^2\left[2B_0B_e - B_e^2\right] + \frac{4KTB_e}{R_L} \tag{4.16}$$

The average P_e is calculated by using the equations (4.15), (4.16) and (3.11).

Chapter 5

Example

Consider a set of N wavelengths corresponding to the number of branches ($N = 1, 2, 3, ...$, there are n number of users per branch ($n = 2^i$,where i is an integer) and data rate for each channel as 2 5 $Gbits/sec$ If the minimum bit rate required per user and the active users at anytime are assumed to be 100 $Mbits/sec$ and 75% respectively then the maximum number of users per branch comes out to be 32. Typical values of parameters used for computations in the system analysis are:

- maximum allowed transmitter power, P_T,0 dBm
- desired BER 10^{-9}
- insertion loss of single 2×2 coupler, L_d,0.5 dB
- insertion loss of splice, L_{sp}, 0.5 dB
- insertion loss of WDM device, L_w,0 5 dB
- fiber attenuation coefficient,α,0.2 dB/Km
- distance between branches, L,5 Km

- receiver load resistance, R_L,100 Ω
- operating wavelength, λ,1 55 μm
- optical bandwidth, $B - 0.25 GH_z$
- electrical bandwidth, B_e, 2.5 GH_z
- receiver temperature, T,300$^o K$
- electron charge, e 1 602 $\times 10^{-19}$ C
- quantum efficiency of PD, η, 1
- responsivity of PD, R_0, 1 28

The total number of users supported by the network and hence the maximum transmission distance is determined by computing the minimum transmitter power required for various values of N The computation is repeated for different values of the number of users per branch,n, and the extinction ratio,ε. The maximum values of n for different bandwidths (minimum) per user are determined as 32, 16, 8 and 4. The effectiveness of OAs with and without saturation is also analyzed.

The supportability has been computed for given P_T and n. For example, when P_T, and ε were assumed to be 0 dBm and 0.05 respectively, the maximum supportable number of users for different values of n were determined and tabulated in the following table.

No. of users per branch	*Total no. of users supported (N_u)*		
n	without OA	unsat OA	sat OA
32	64	448	192
16	48	240	112
8	40	136	64
4	24	72	40

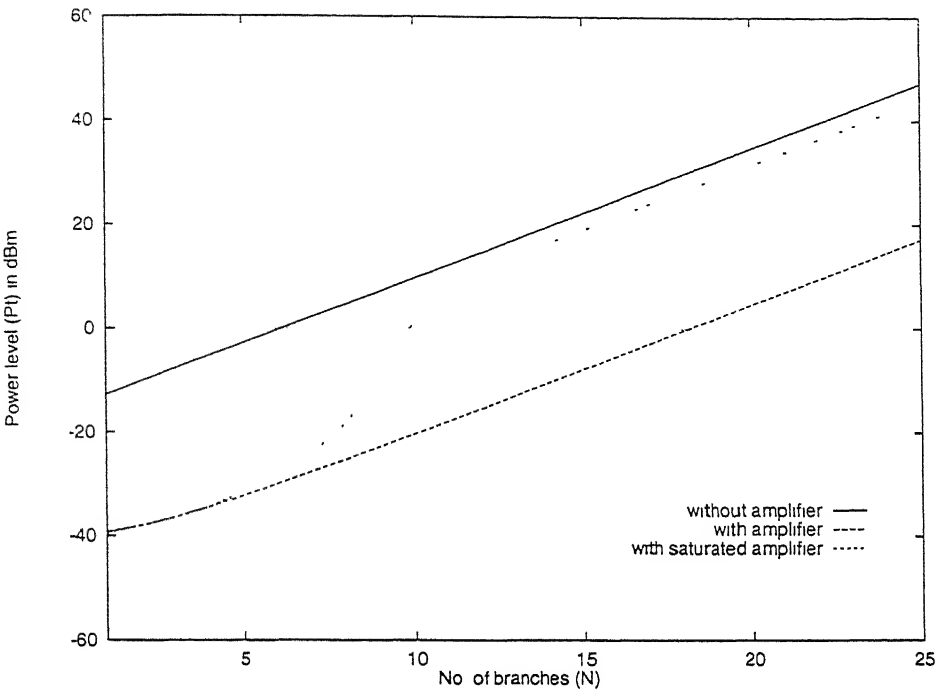

Figure 5.1: Variation of P_T Vs N for n=4 and eps=0.05

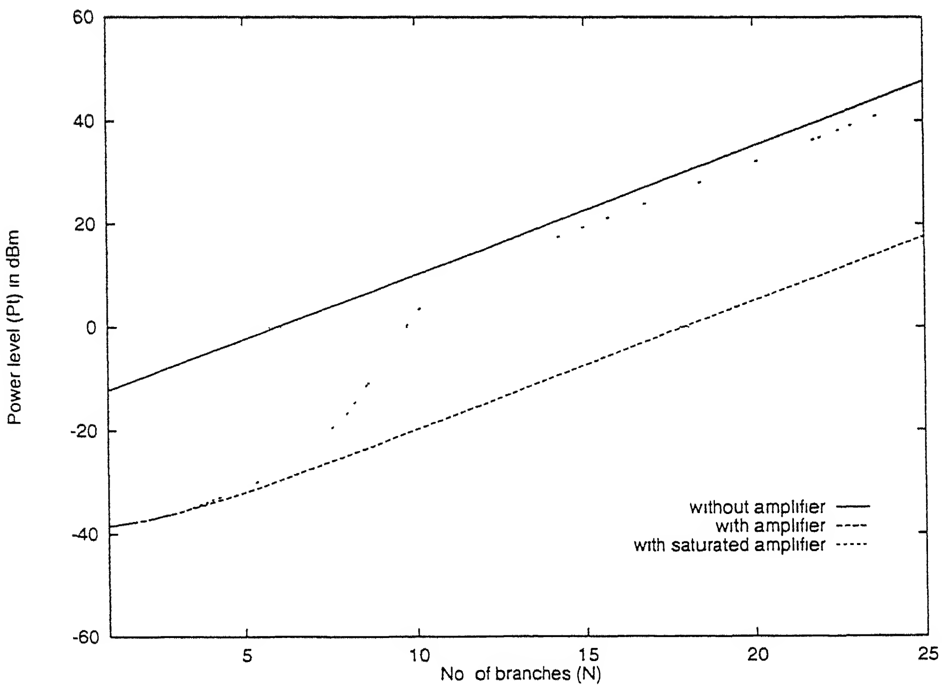

Figure 5.2: Variation of P_T Vs N for n=4 and eps=0.10

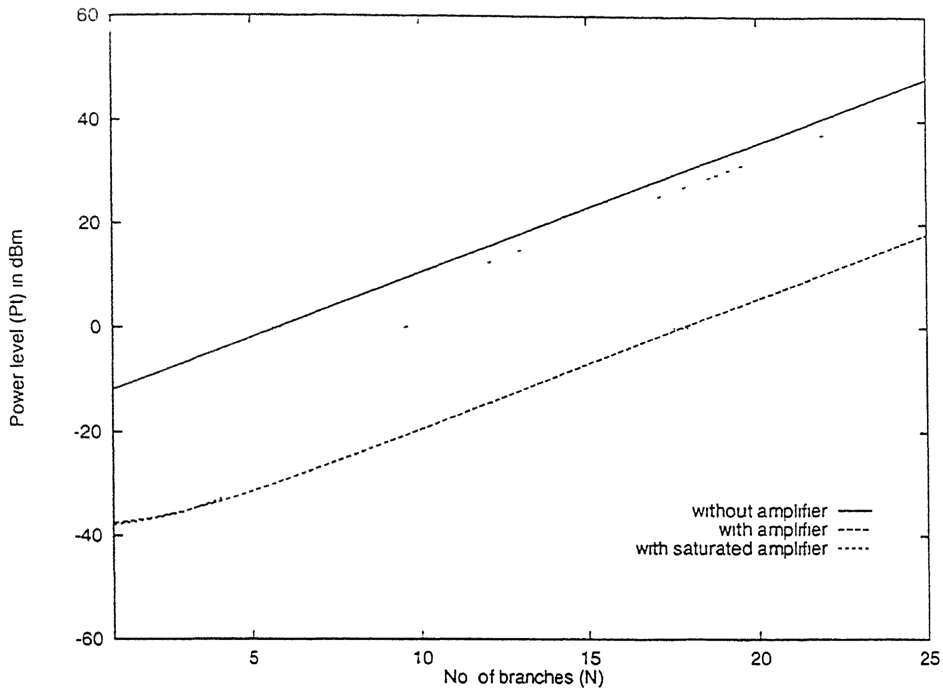

Figure 5.3. Variation of P_T Vs N for n=4 and eps=0.15

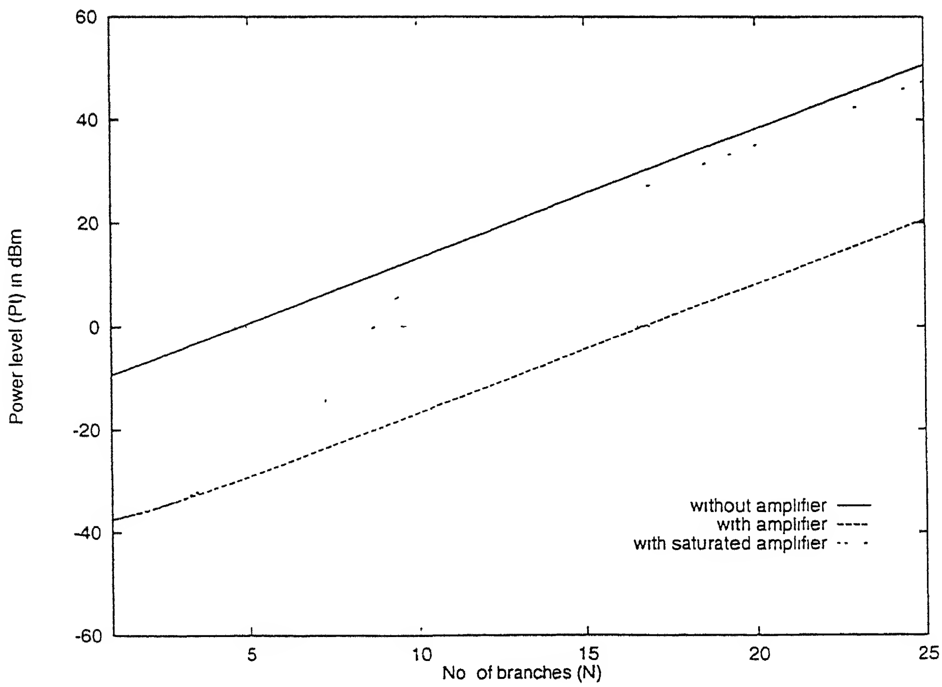

Figure 5 4. Variation of P_T Vs N for n=8 and eps=0.05

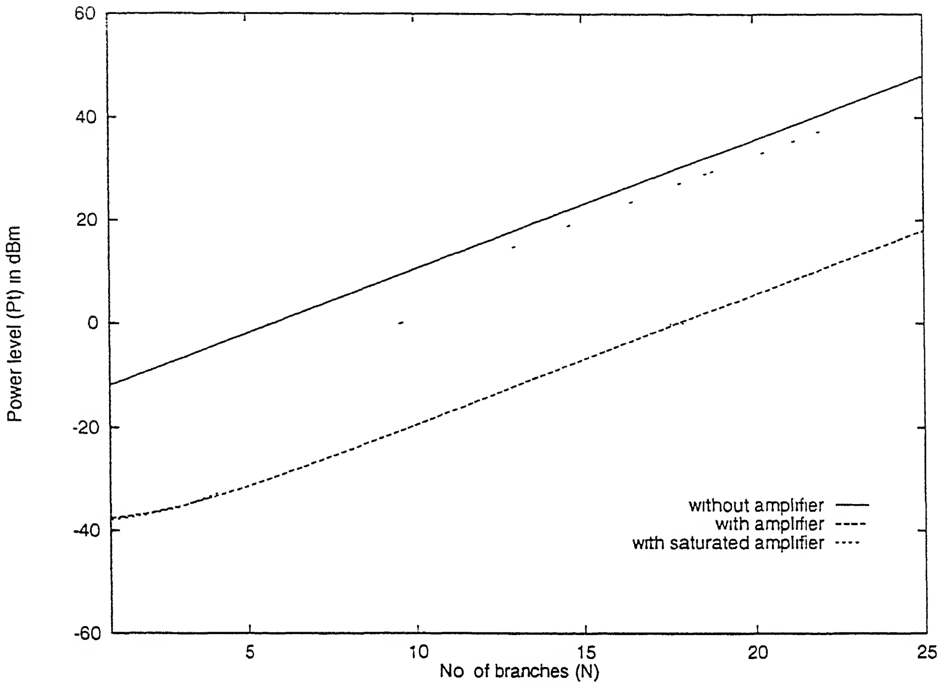

Figure 5.3: Variation of P_T Vs N for n=4 and eps=0 15

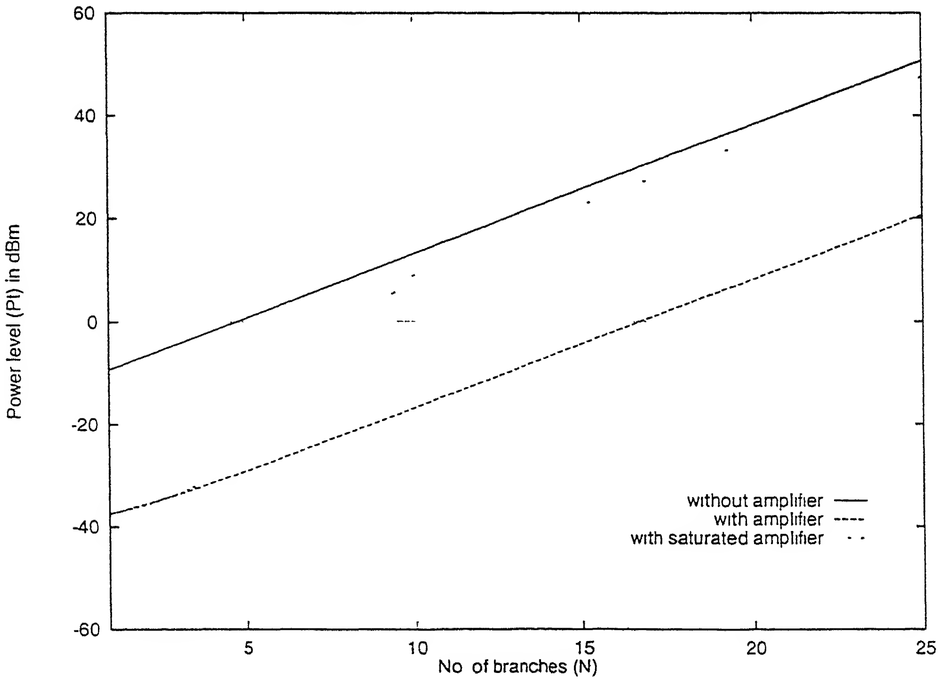

Figure 5 4· Variation of P_T Vs N for n=8 and eps=0.05

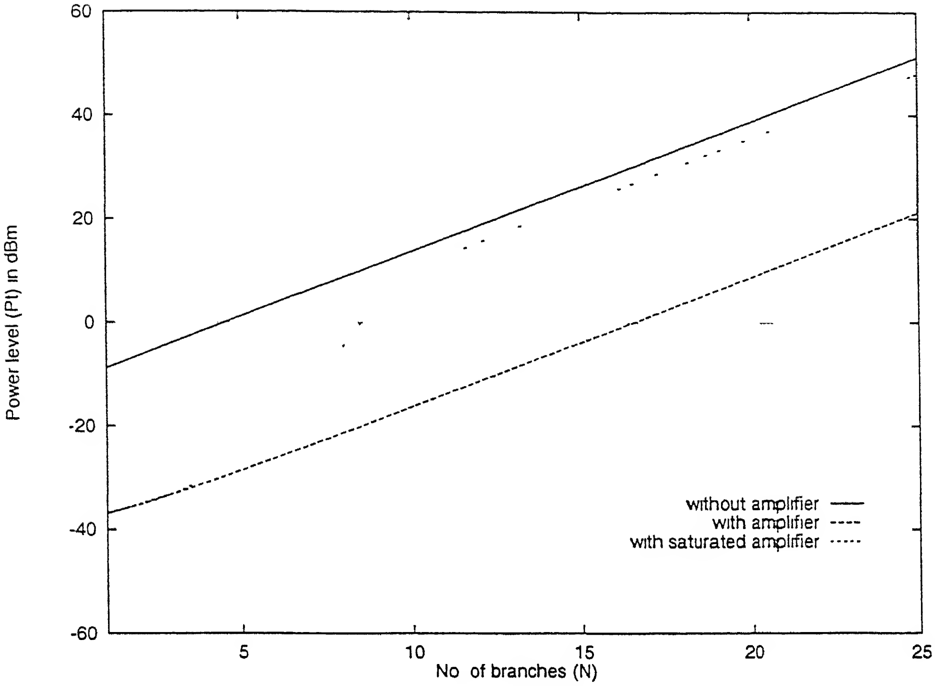

Figure 5.5: Variation of P_T Vs N for n=8 and eps=0.10

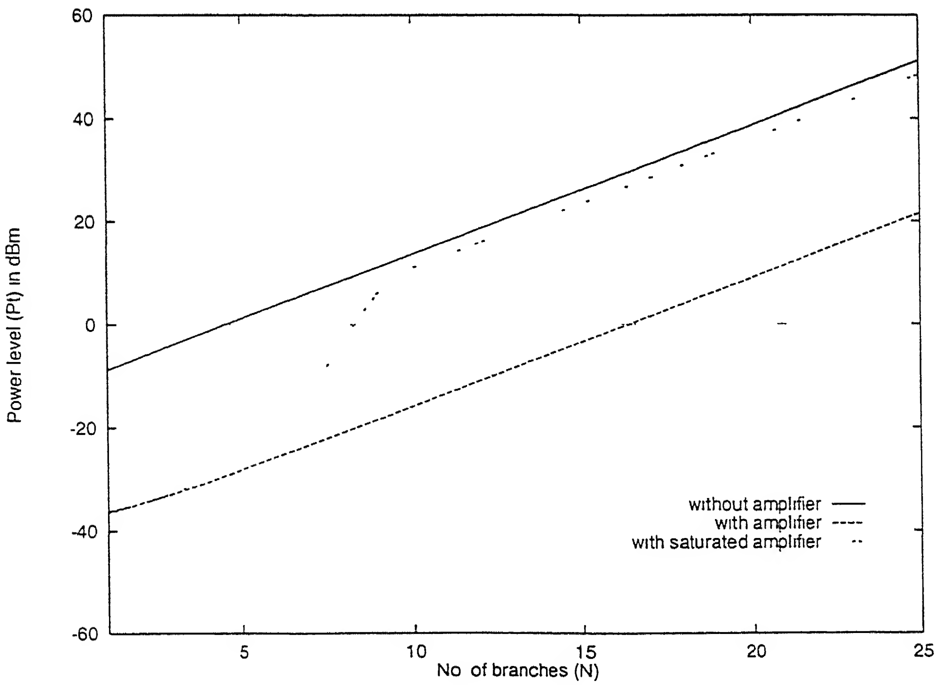

Figure 5.6 Variation of P_T Vs N for n=8 and eps=0.15

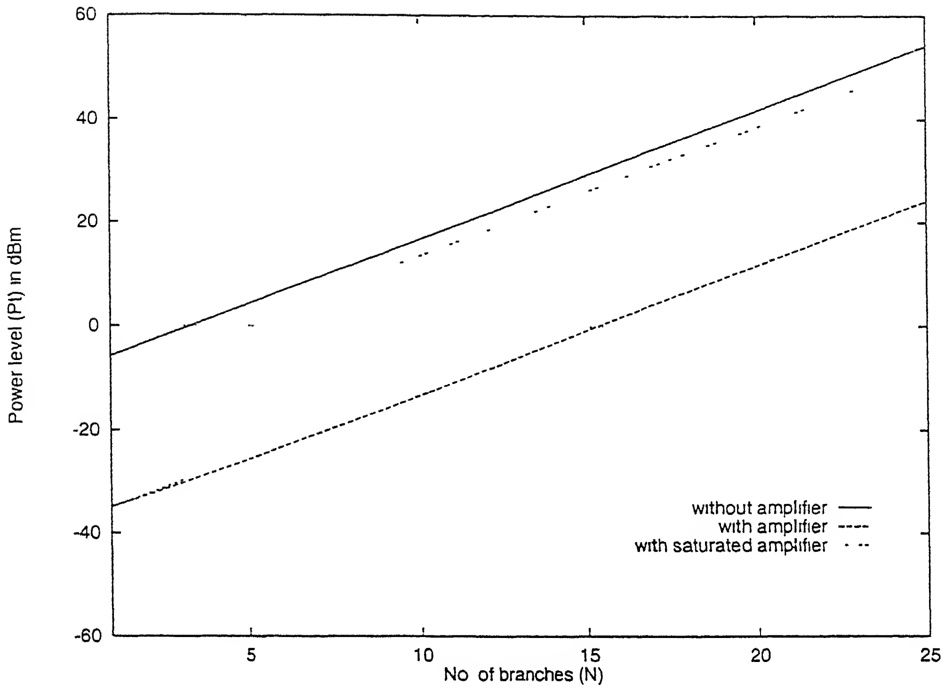

Figure 5.7: Variation of P_T Vs N for n=16 and eps=0 05

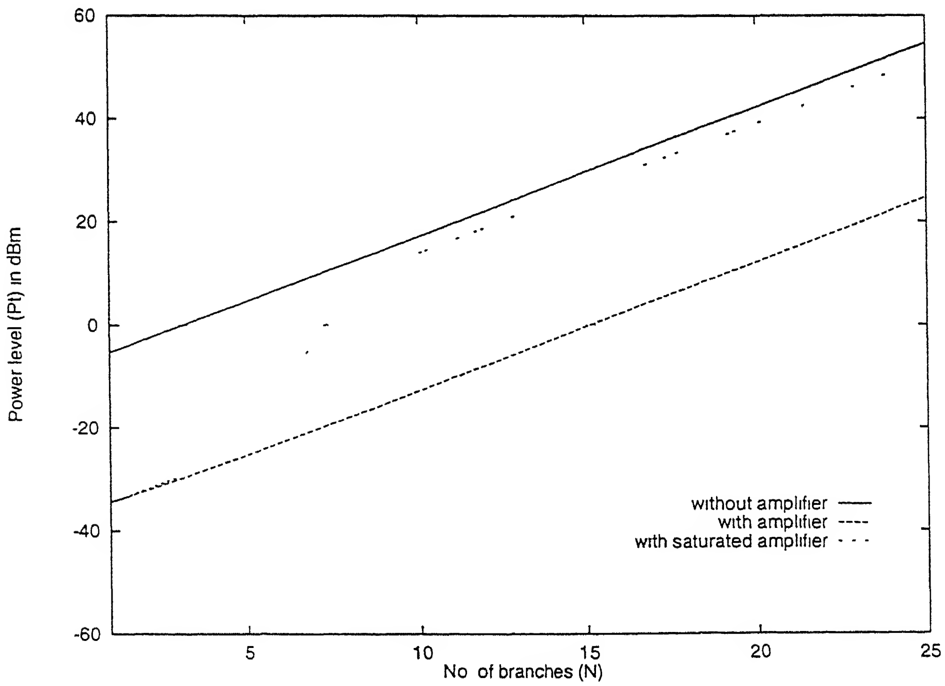

Figure 5 8: Variation of P_T Vs N for n=16 and eps=0.10

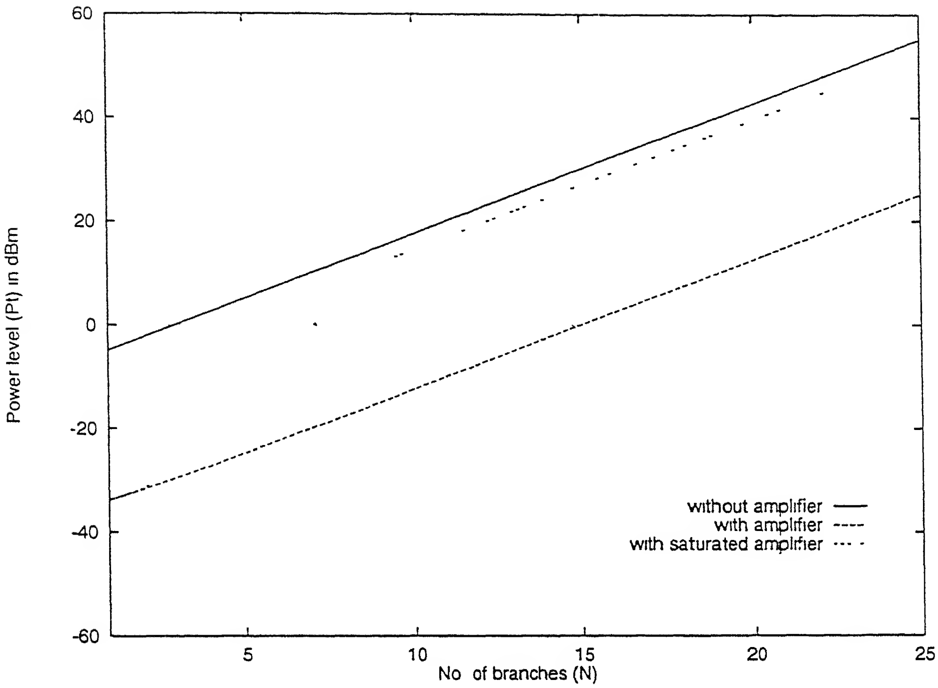

Figure 5.9: Variation of P_T Vs N for n=16 and eps=0 15

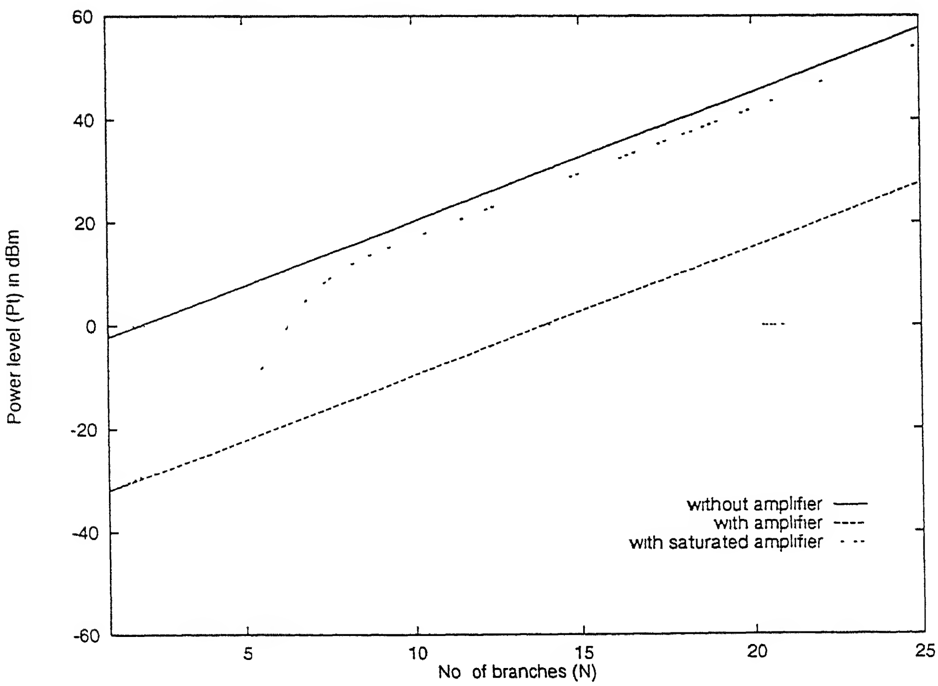

Figure 5.10: Variation of P_T Vs N for n=32 and eps=0.05

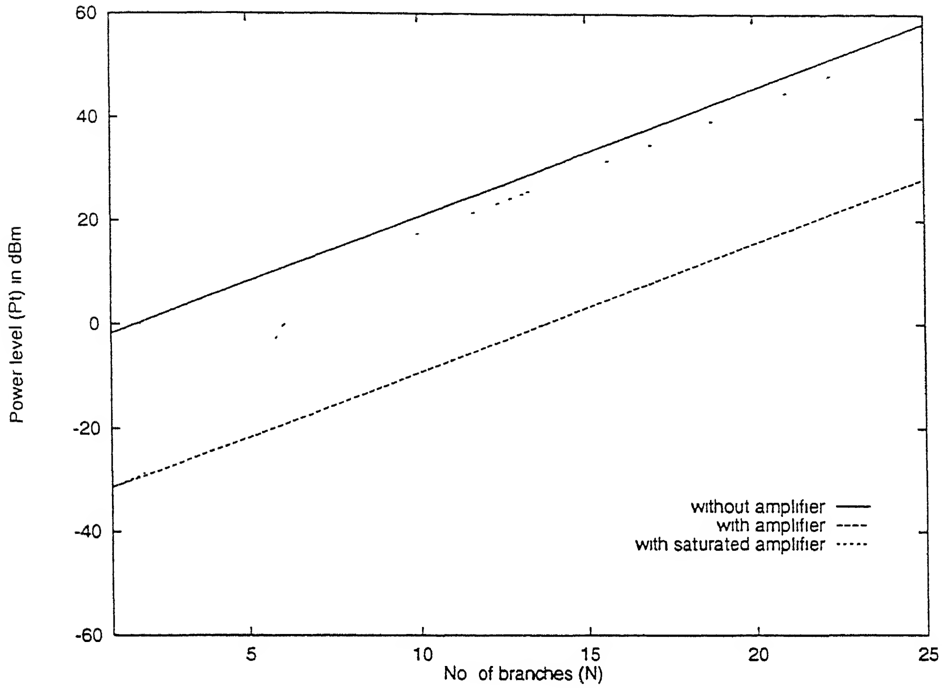

Figure 5.11: Variation of P_T Vs N for n=32 and eps=0.10

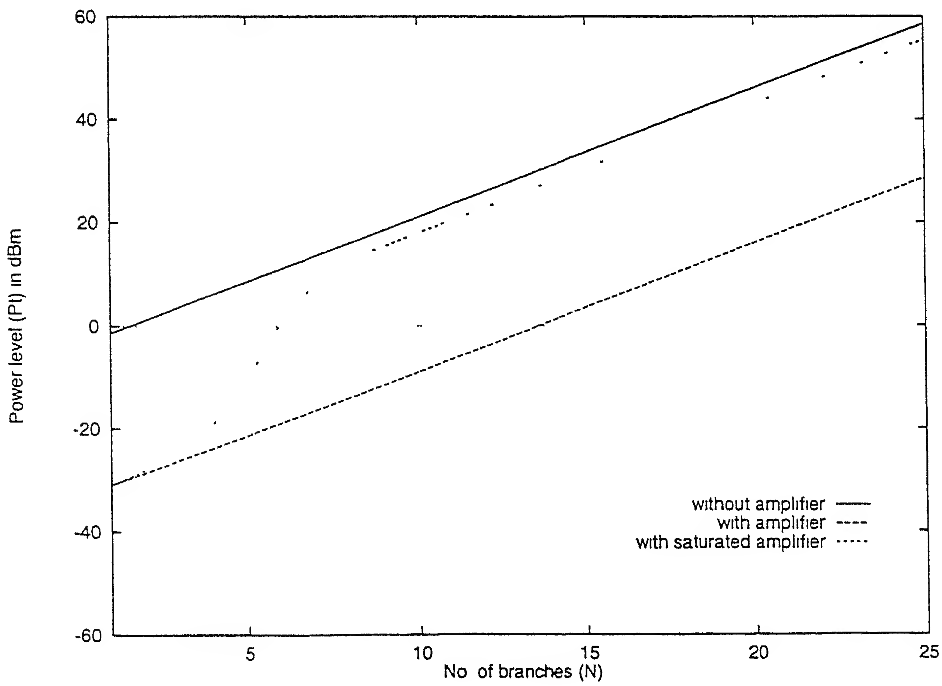

Figure 5 12: Variation of P_T Vs N for n=32 and eps=0.15

The above table shows that when the number of users per branch is reduced for a given P_T the supportability of the system is also reduced with increase in transmission distance. For example, when n is halved, the bandwidth per user is doubled The table also shows that the throughput which is defined as product of the total number of users and the bit rate per user is increasing with decrease in n. The variation of P_T with N for different values of n and ε has also been computed The results are shown in figures 5.1 to 5.33 The important observations along with the effects of amplifier's gain saturation, and the extinction ratio are discussed based on these figures.

a) The use of optical amplifier with or without gain saturation always reduces the minimum required P_T as compared to the without amplifier case (see figures 5 1 to 5.12)

b) When N is less (say $N \leq 5$), the effect of gain saturation is not severe and the required P_T is comparable with that of unsaturated amplifier case(see figures 5.1 to 5.12)

c) For large values of N, the power penalty increases and the system performance is degraded due to the gain saturation effect This is due the increase in the total input power in order to maintain the given BER when the losses are increased in the system(see figures 5.1 to 5.12).

d) Though, the saturation effect of the amplifier degrades the system performance, it supports more number of users as compared to without amplifier case(see figures 5 1 to 5.12)

e) For the given n the effect of ε is determined in all the three cases and found that the extinction ratio is not giving any noticeable effect on the variation of P_T(see figures 5.22 to 5 33).

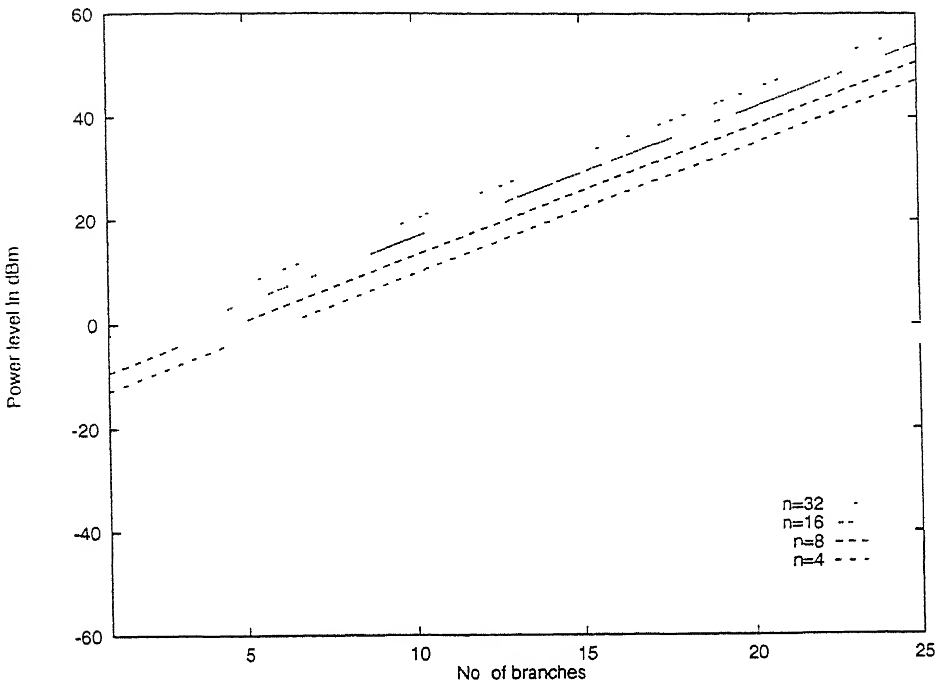

Figure 5.13: Variation of P_T Vs N without amplifier for eps=0.05

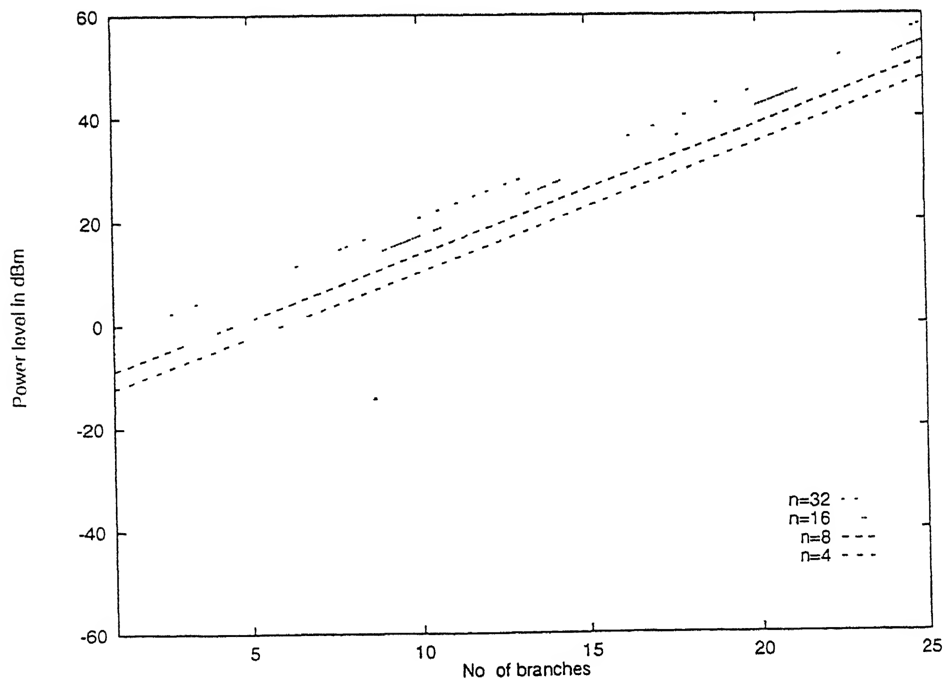

Figure 5.14: Variation of P_T Vs N without amplifier for eps=0 10

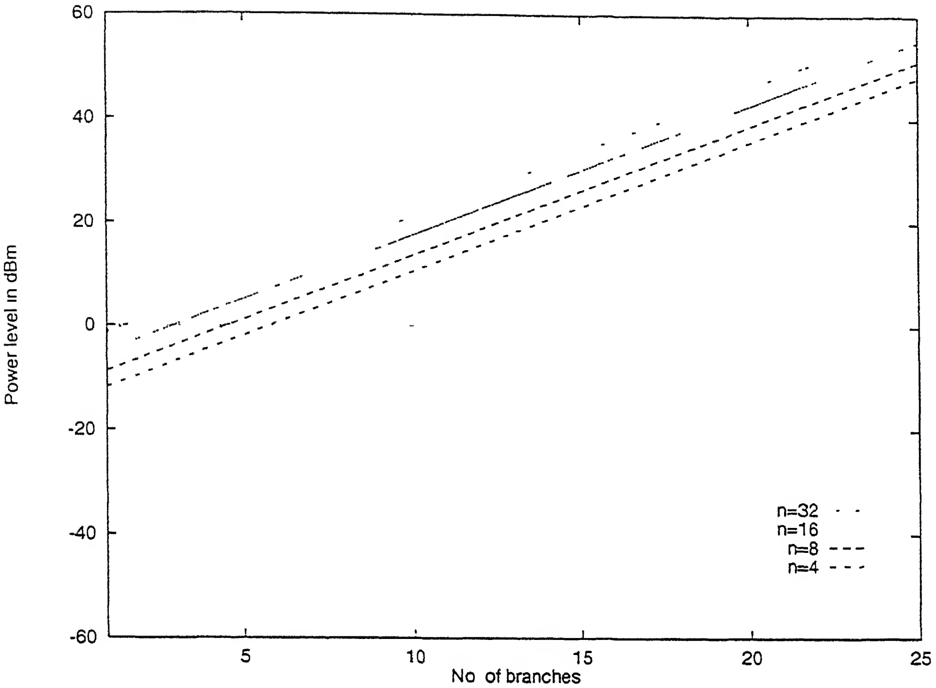

Figure 5 15· Variation of P_T Vs N without amplifier for eps=0.15

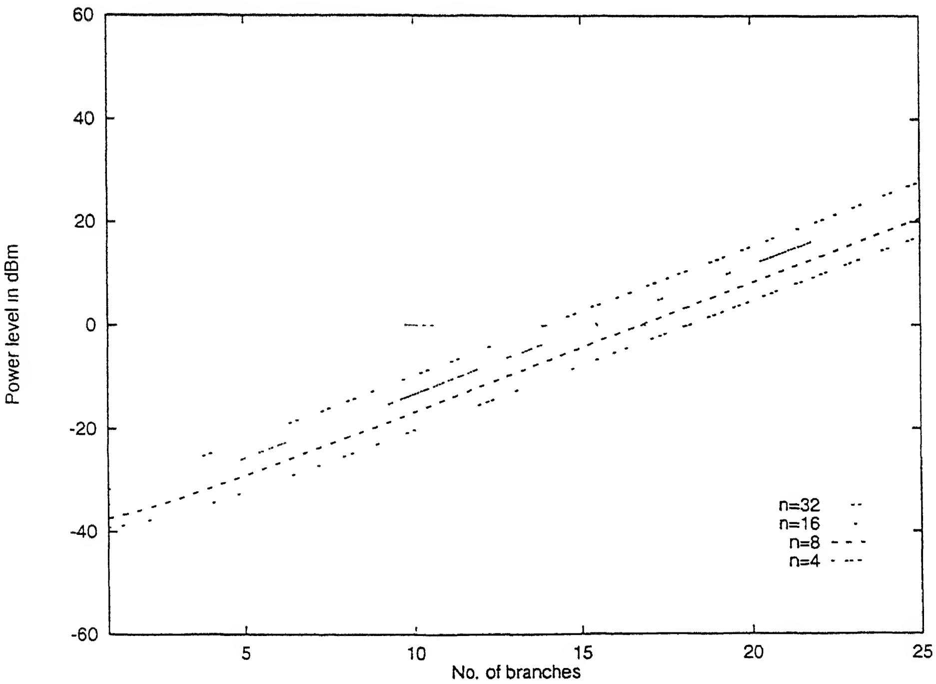

Figure 5.16: Variation of P_T Vs N with amplifier for eps=0.05

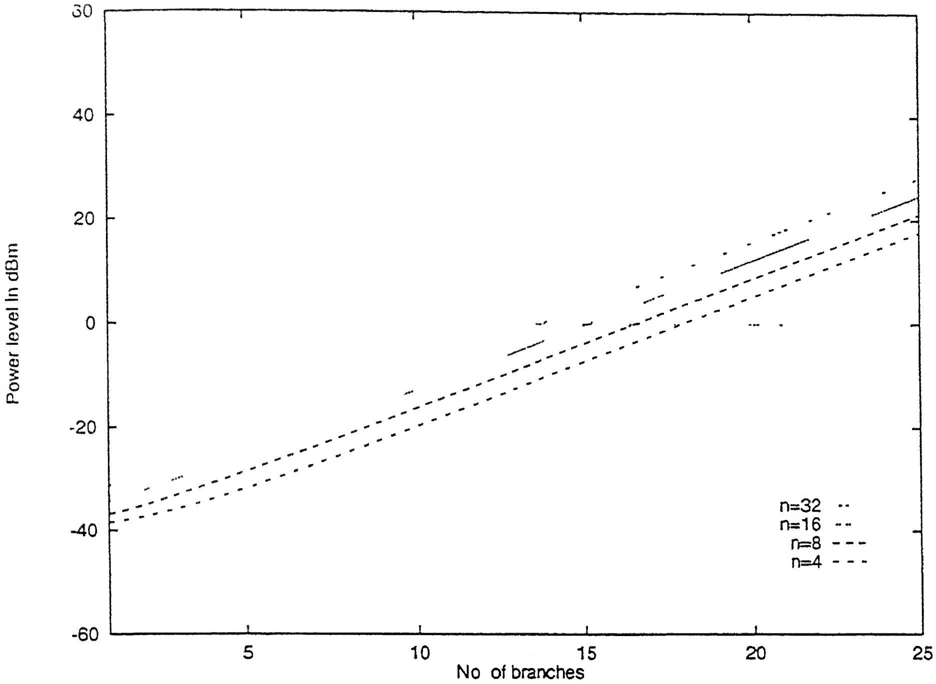

Figure 5.17: Variation of P_T Vs N with amplifier for eps=0.10

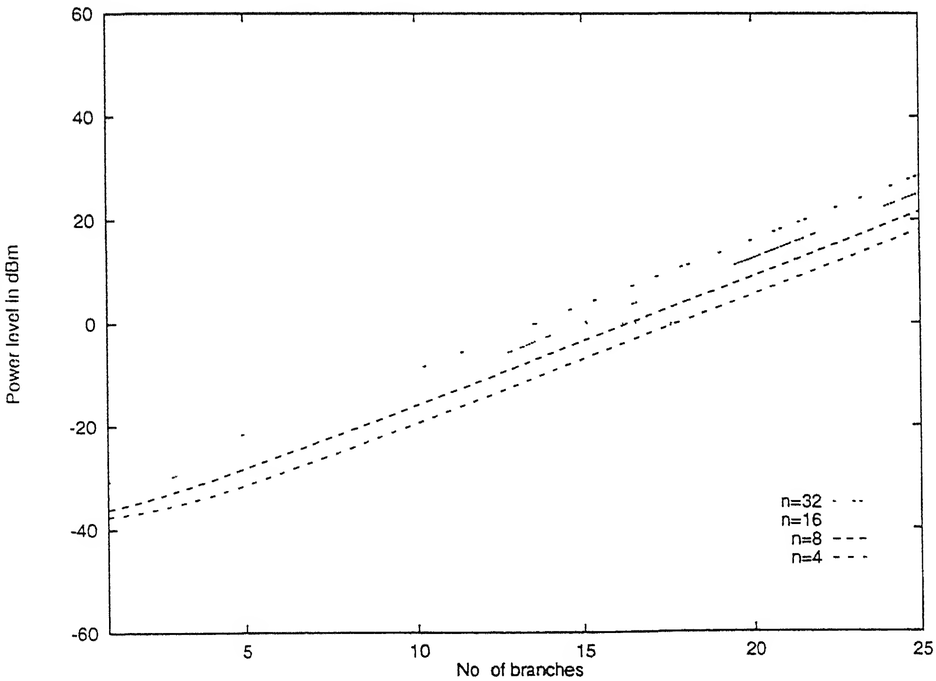

Figure 5.18: Variation of P_T Vs N with amplifier for eps=0.15

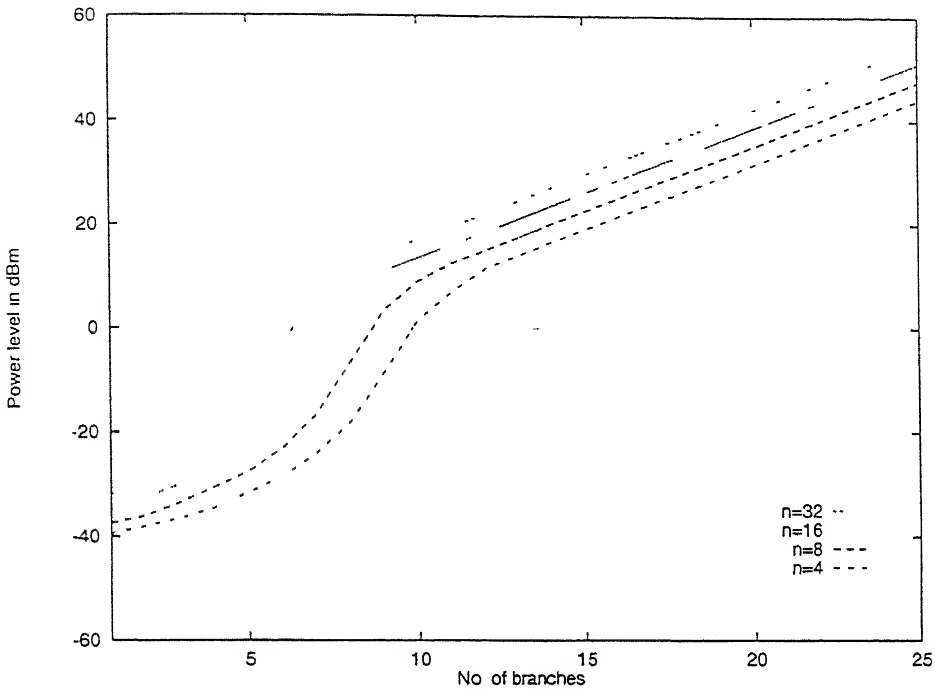

Figure 5.19. Variation of P_T Vs N with saturated amplifier for eps=0 05

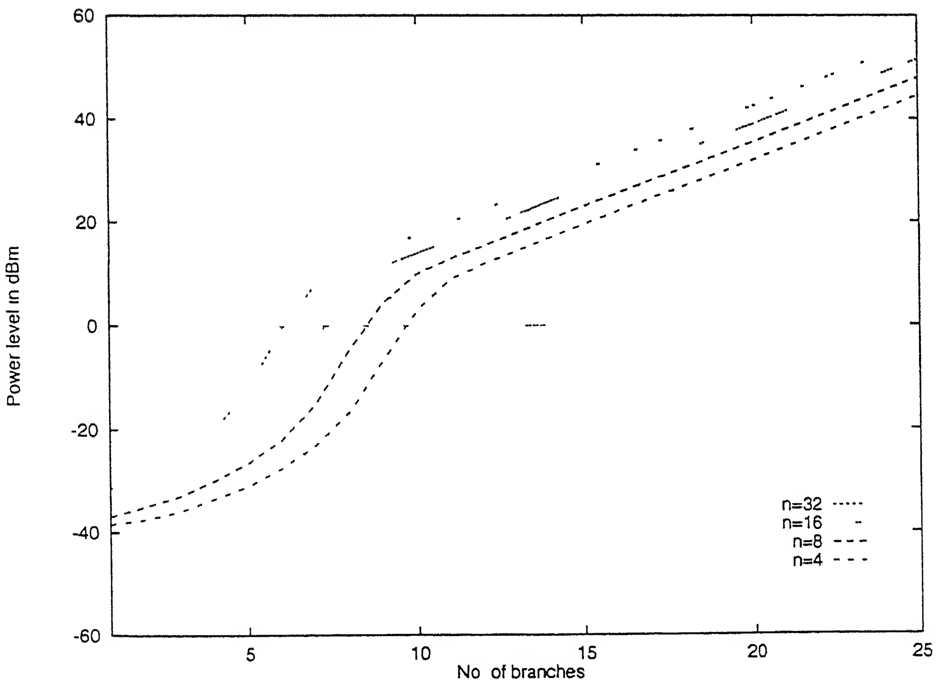

Figure 5.20: Variation of P_T Vs N with saturated amplifier for eps=0.10

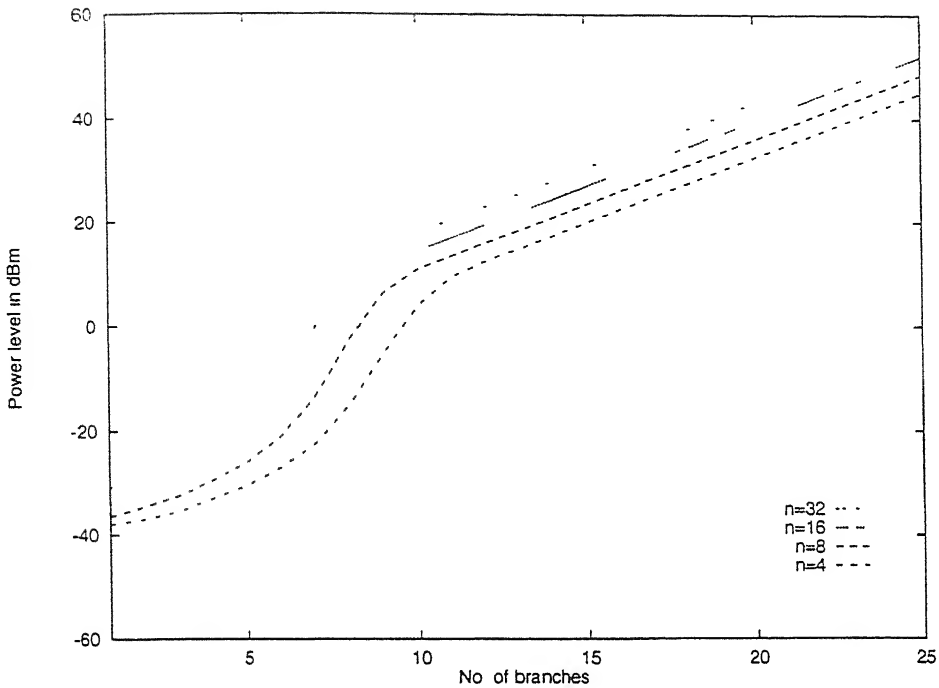

Figure 5.21. Variation of P_T Vs N with saturated amplifier for eps=0.15

f) Variation of P_T for different values of n (say,32,16,8 and 4) at particular value of ε in three cases is also studied and found that the minimum required P_T is decreasing with decrease in n for a given N (see figures 5.13 to 5.21)

g) In the without amplifier case, the variation of P_T with N for different values of n and ε is compared. The same procedure is repeated for amplifier with and without gain saturation It is found that the reduction in the minimum required P_T with respect to without amplifier case is approximately same for small values of N for both with and without gain saturation (see figures 5.1 to 5.21).

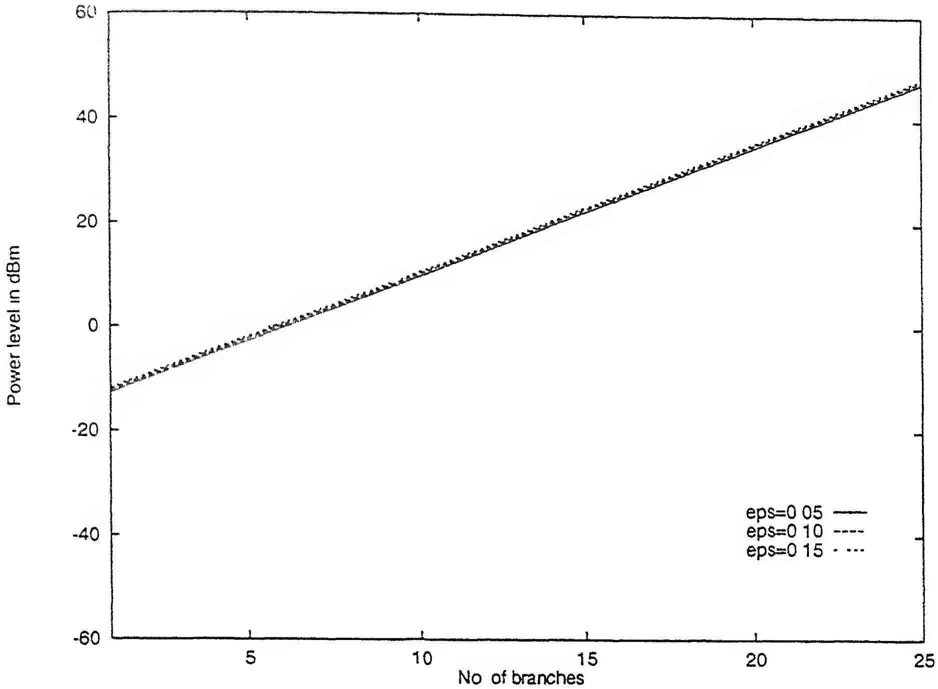

Figure 5.22: Variation of P_T Vs N without amplifier for n=4

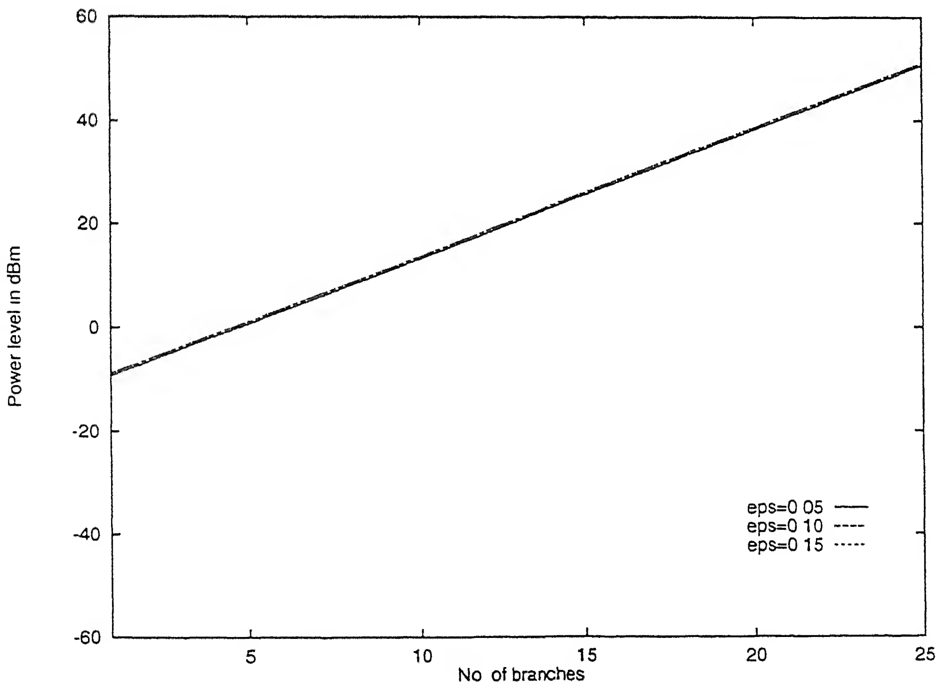

Figure 5.23: Variation of P_T Vs N without amplifier for n=8

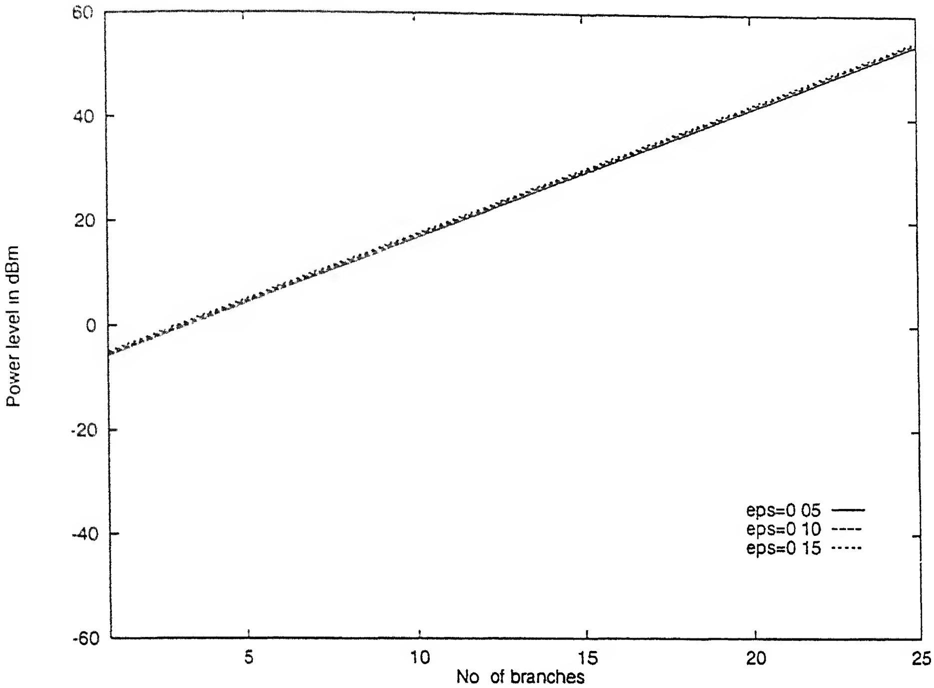

Figure 5.24: Variation of P_T Vs N without amplifier for n=16

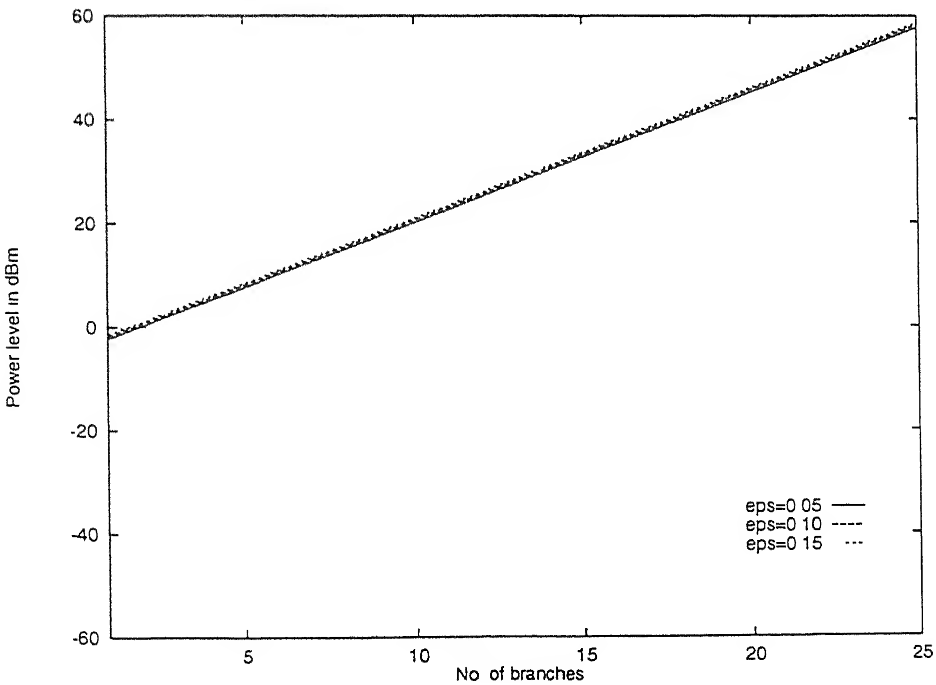

Figure 5.25: Variation of P_T Vs N without amplifier for n=32

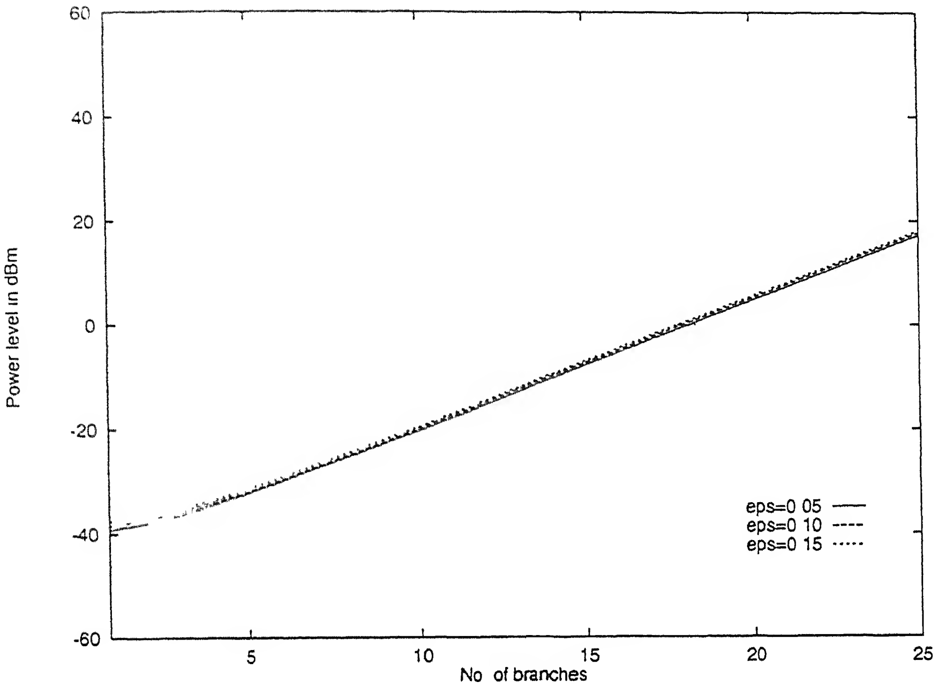

Figure 5.26: Variation of P_T Vs N with amplifier for n=4

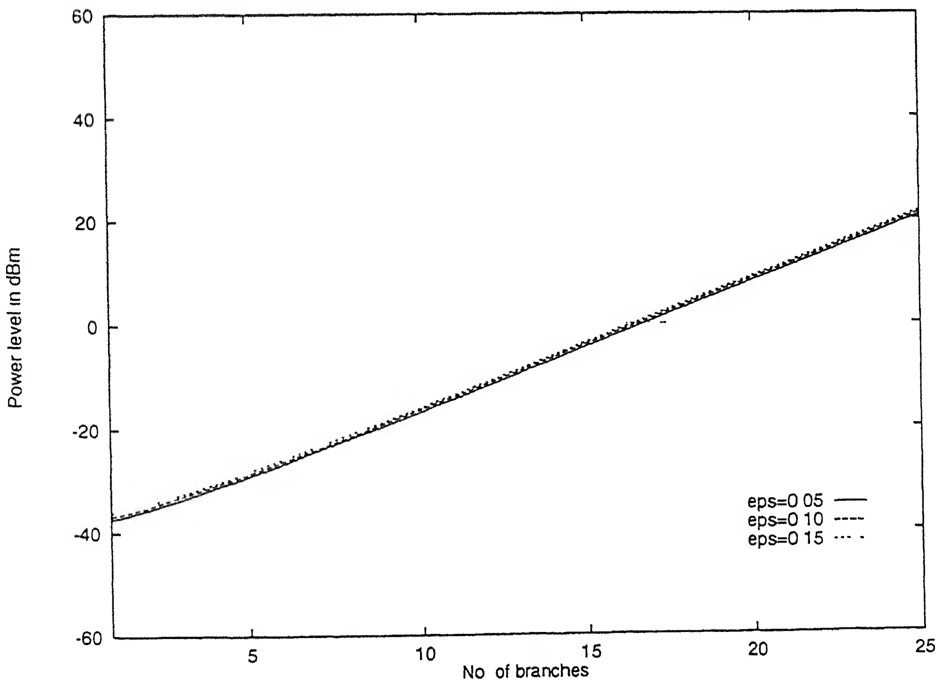

Figure 5.27: Variation of P_T Vs N with amplifier for n=8

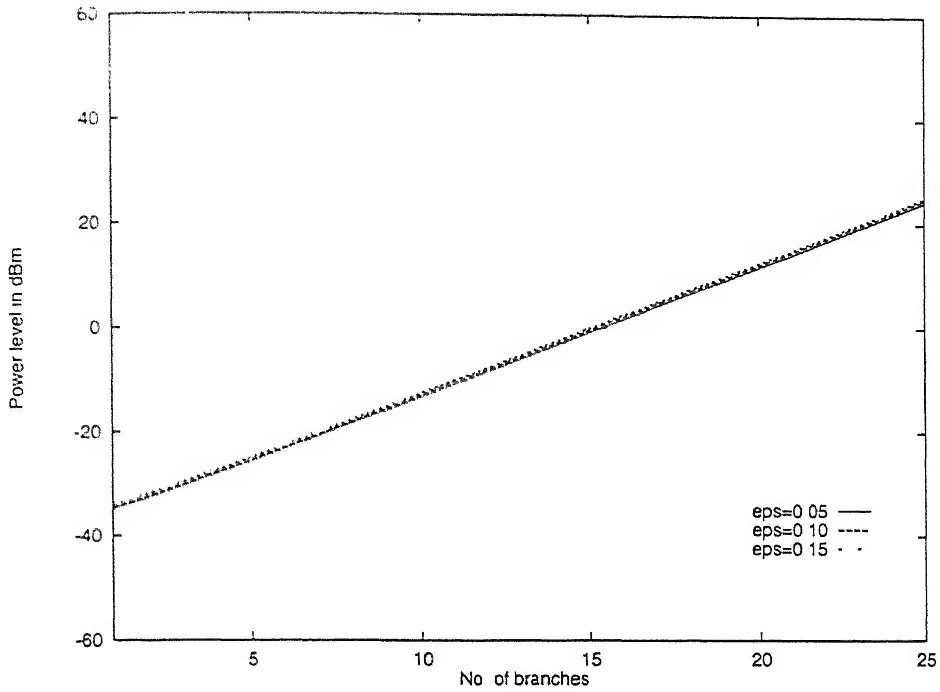

Figure 5.28. Variation of P_T Vs N with amplifier for n=16

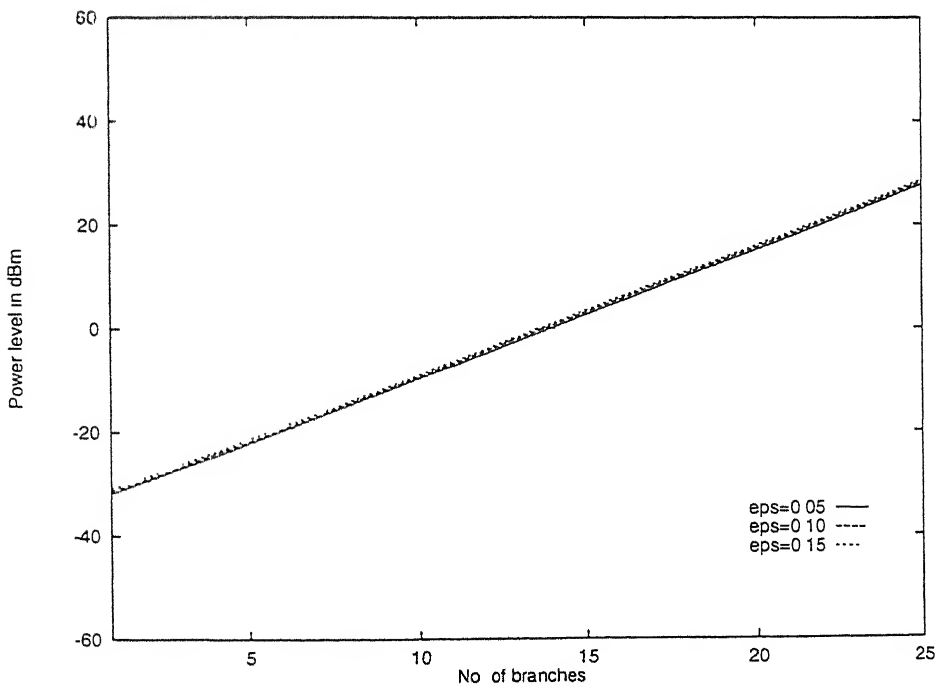

Figure 5.29: Variation of P_T Vs N with amplifier for n=32

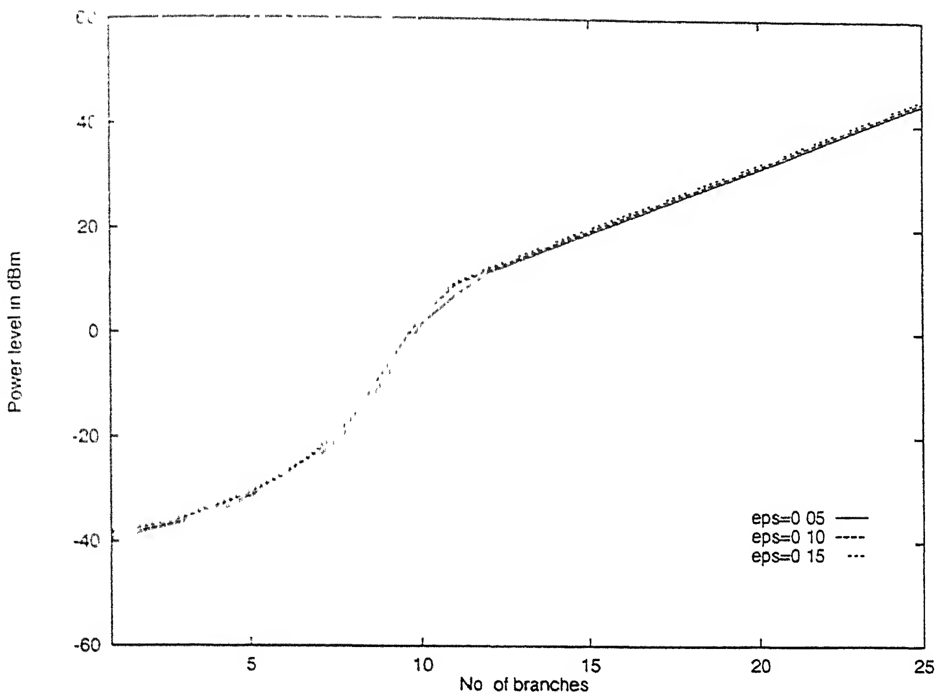

Figure 5.30. Variation of P_T Vs N with saturated amplifier for n=4

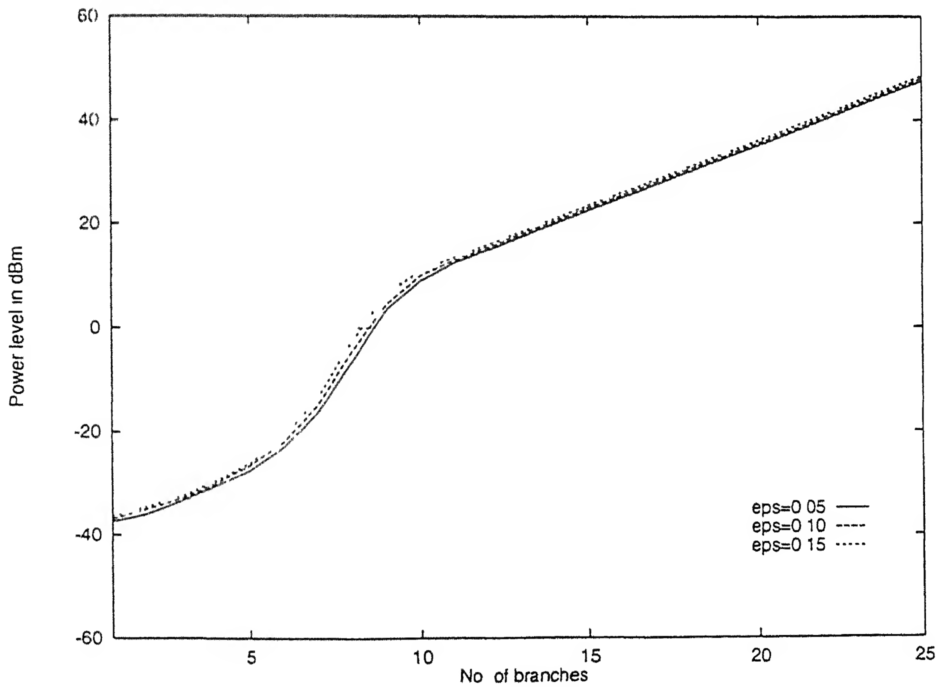

Figure 5.31: Variation of P_T Vs N with saturated amplifier for n=8

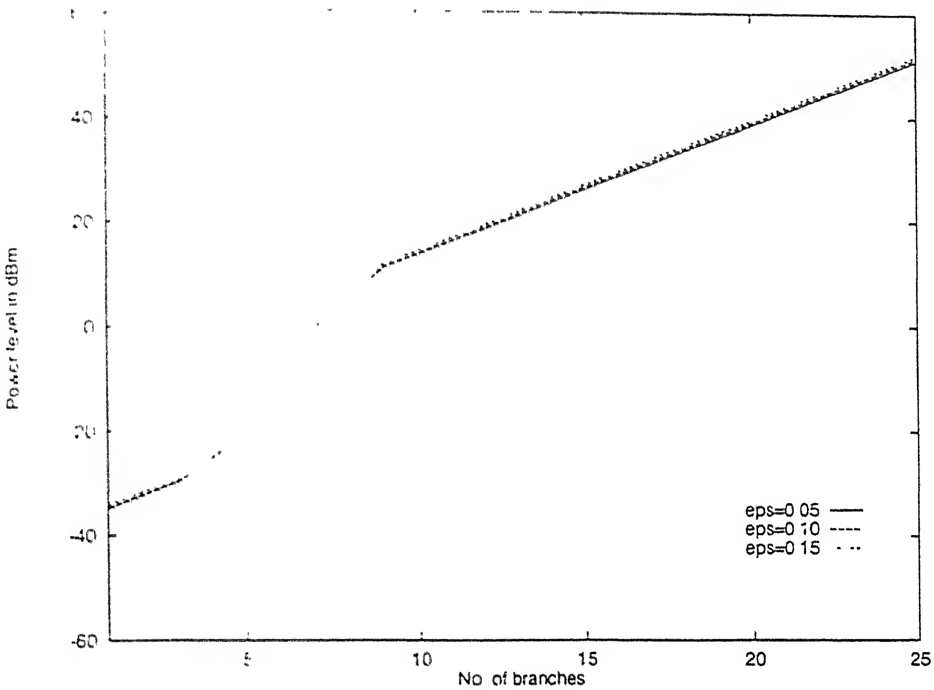

Figure 5 32: Variation of P_T Vs N with saturated amplifier for n=16

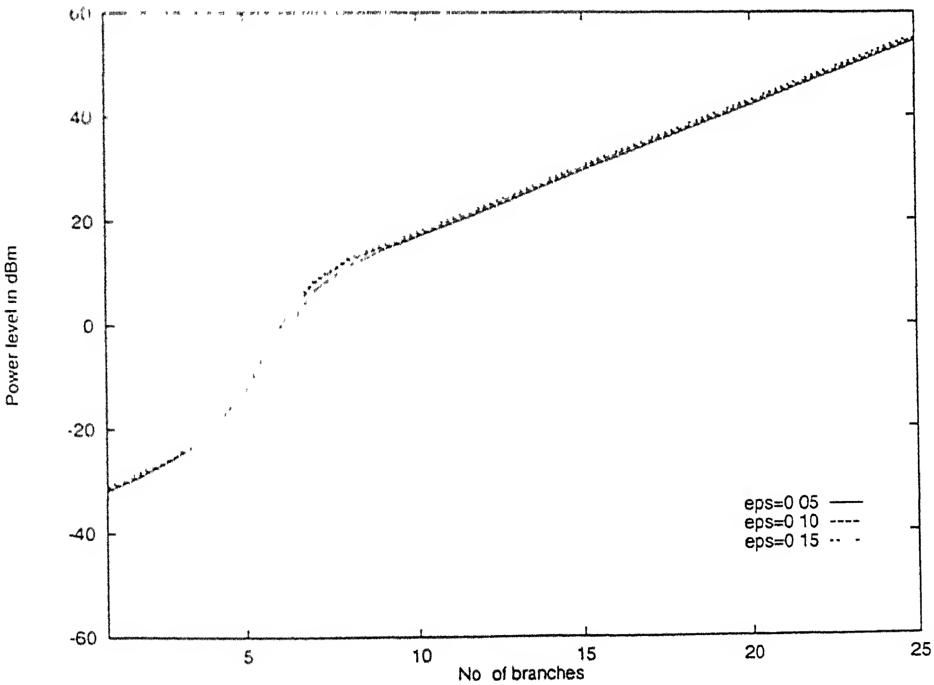

Figure 5 33: Variation of P_T Vs N with saturated amplifier for n=32

Chapter 6

Conclusions

A new architecture of the subscriber access network was proposed. Before discussing the proposed network, already proposed networks and topologies were discussed from system upgradation point of view. In the new system architecture, the supportable number of users was computed. The incorporation of optical amplifiers in the network for increasing the capacity and the effect of gain saturation were analyzed. The effect of extinction ratio was also computed. From the foregoing discussions it is found that the proposed network can support large number of users for given number of amplifiers as compared to other networks. The system performance is degraded by the gainsaturation effect of the amplifier but the supportable number of users is still high with respect to without amplifier case.

In this analysis, the crosstalk effect is not considered since the available components such as WDM, OADM and coupler are crosstalk free devices. Further, the system can be expanded to cover long distance and supports more users by placing the optical amplifiers at proper distance on the less. While doing so the total ASE noise contributed from each amplifier should be considered.

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